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ON SENSORY INTERACTION IN JUDGEMENT OF VELOCITY AND ITS MEASUREMENT BY PSYCHOPHYSICAL SCALING METHODS

by

CHRIS OTTANDER

STOCKHOLM 1967

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Inaugural dissertation

by

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Chapter 1

Interrelations between senses

It has long been the custom to state that perception seldom depends on the stimulation through one single sense modality only. Again and again authors of textbooks describe perception as the joint result of the complex stimulus array hitting all our senses at a given moment. It is further pointed out that a living organism does not react to everything in this array but selects and organizes certain parts of the complex stimulus impact.

The same textbooks then go on to describe perception, taking visual perception as their favourite example and sometimes continuing with, usually shorter, descriptions of some three to eight senses each described in isolation (see e.g. Boring, Langfeld, Weld (1948), Murphy (1951), Stevens (1951), Geldard (1953) or Deese (1964).

Thus, parallel with the repeated statement of the importance of sensory intra- and inter-relations, there is a tradition—experimentally at least—of treating each sense modality as a unique, isolated entity.

Naturally, there are psychologists who take up the question and discuss it to some extent (Bartley (1941) (1958), Pieron (1953), Dember (1960), Gibson (1966)). For these authors Bartley (1958) may be accepted as a good spokesman. He starts his chapter (ibid. chapter 4) on sensory interrelations by stressing that in experimental situations it is difficult or impossible to avoid the operation of senses collateral to the one under study. He continues:

"Often, when the participation of senses other than the one under study is recognized, it is taken to be negligible in its influence upon the experimental results. At other times, if not negligible, it is looked upon as something having constant influence, so that it can be taken as a 'constant error'."

Bartley continues in a rather depressed mood:

"Be that as it may, all too little has been done by psychologists and other biologists directly to study sensory interrelations. Their study is the exception rather than the rule."

A would-be-researcher, looking for help, could certainly be more encouraged.

Anyhow, recent theorizing in perception and learning, e.g. Helson (1948, 1964), Hebb (1949), Werner and Wapner (1952), Brunswik (1956), Sokolov (1963), and Gibson (1966) have counteracted the traditional view of the senses as isolated systems, although the general impact on experimental work hitherto has been small—at least within psychology.

The problem seems to have been given as new impetus by a review done by London (1954) of work done on sensory interaction in the Soviet Union. London presents and discusses a series of Russian investigations in the field and the results are puzzling and fascinating.

Dember (1960) is—as far as the author knows—the first textbook to cite this material in a mere general setting.

Although most of the references cited so far either avoid the problem of sensory interaction or tell us that almost nothing is done in the field (outside of the Soviet Union), one can find an old experimental tradition dealing with the problem of sensory interaction starting with Urbantschitsch (1888). It should perhaps be mentioned at this stage that the number of investigations the present author is going to review is not large. This review does not pretend to be a full exposé of what has been done so far but will merely serve as a representative sample of experimentation up to the present time, out of which the author will select a small part and on which to focus his interest.

After this challenging critique of experimental work on perception, a suitable aim for this text ought to be to establish sensory interaction as the focus of interest within perception.

The author has a good many reasons—some of them rational—for not doing so. Some of these will be presented in the text further on. One reason will be given immediately.

In his introduction, Hebb (1949) discusses the need for simplification, or even oversimplification, in handling the complexity

of perception. I think this is one good reason for not pushing the cause of sensory interaction too far. Too many facts are still missing for us to be able to build a workable theory of perception. But let us follow up Hebb's reasoning. In applying the over-simplification mentioned above—and I am here alluding to the traditional handling of each sense modality as an isolated system working by itself—one is running at least two risks. One is to forget that the simplification has been applied, and that seems to be a frequent error. The other risk is a direct effect of the first. In accepting this simplification, relevant new approaches might not be sought for, and even if they are stumbled upon, there is a tendency to disregard them.

And this gives me a fairly rational motive for the present work.

The first aim of the present work is to discuss and clarify some of the concepts used in dealing with sensory interaction. In order to do this some general key concepts will be selected, and these will constitute the frame of reference. Within this frame, a number of investigations will be described in order to illustrate alternative explanatory approaches. The definition of some of the concepts used in these approaches will then be scrutinized.

To a certain extent this discussion is anticipating the research strategy to be described later. It might naturally be argued that this order of presentation may require a great deal of anticipatory goal reactions from the reader, but I have found it convenient in order to strip the subject down to a manageable size. This discussion thus gives some of the reasons for choosing an exploratory approach in the actual series of experiments to be presented later.

The next part in the present work is a review of some experimentation performed on what here is called sensory interaction. This part gives a more specific basis for my own experiments as regards background, research strategy, choice of methodology and choice of the actual subjective attributes to study.

The main aim is to investigate whether certain types of sensory interaction—more specifically occurring as influences on estimation of velocity, time and distance in a geometrical illusion—could be studied and measured by psychophysical scaling methods. It is hoped that this work will yield alternative methods to those

commonly used in this field namely classical psychophysical methods for threshold measurements.

Another problem dealt with to some extent is the question of whether the results from sensory interaction-experiments reveal anything beyond effects or changes in the subjects response-habits, i.e. are the effects observed to be considered as examples of response bias or are they "true" changes in the perception of the subjects in the sense that different methods give the same results irrespective of varying possibilities of response bias? In this connection sensory interaction effects affected by practice are taken up and certain connections found between sensory interaction and so-called perceptual learning.

Chapter 2

Naming and limiting the field of study

2.1 *Introduction*

When approaching the field of sensory interrelations or sensory interaction (accepting the two expressions as being synonomous for the present), the first problem is one of setting up initial—perhaps crude and naturally arbitrary—limits for what is going to be referred to as the phenomenon. It is felt that the stressing of the problem's importance for perception in general simultaneous with the tendency to ignore it, may reflect confusion of definition rather than a genuine lack of interest. I will return to this last point later on.

An essential part in cutting out sensory interaction problems from other perceptual phenomena is dependent on the definition of the concept of sense modality, sense, sense department or only modality (to be used interchangeably). A strict definition of the term sense modality ought to make it possible to refer to perceptual events as emanating from a single sense or as being the compound result of the workings of two or more—and the later situation could then be referred to as an instance of sensory interaction.

2.2 *The traditional definition of the concept sense modality*

In logic the term modality refers to that property of a proposition which asserts, or denies, the possibility of the assertion set forth; or is an expression of a sequence of necessity. Thus, in psychology, the concept sense modality is defined in terms of a number of antecedent criteria to be met. It is traditional to set up four criteria to be fulfilled in order to classify sensory-perceptual events into categories denoted by the names of special senses.

The first criterium is the existence of a unique experience, the second the existense of a specific end-organ for the experience

reported. Third is that the existence of a separate pathway from the end-organ to the brain should be demonstrated and fourth that a specific energy (or range of energies) should be proven to be the stimulus for the unique experience.

Let me list the four criteria used in the definition and then have a closer look at each of them.

1. Unique experience
2. Separate end-organ
3. Separate pathway between the end-organ and the brain
4. Specific energy or range of energies functioning as stimulus.

For illustrative purposes I will try to discuss the four criteria above by roughly following the historical development in the usage of the concept of sense modality from the traditional and strict definition employed by e.g. Sherrington to the more recent vague meaning and application of the concept.

2.3 *A discussion of the four criteria used in the definition of sense modality*

The first observation that can be made is that the four criteria used deal with four basic and controversial problems in psychology (and to some extent physiology). Criterium 1 throws us into the involved question of definitions of perception and sensation. Let us confine ourselves to the qualitative aspect of the concept *unique* and for the moment disregard differences in the meaning of the concepts perception and sensation. We might then ask what the words *unique experience* stand for? A frequently used group of terms used to shed some light on this question are experience, hypothesis and perception. If we think of perception as some neural concomitant with the subjective experience we can talk of the setting up of hypothesis as an intermediate cognitive process. Then what this comes down to, is to state (in rather obscure terms) that some kind of phenomenological report is inevitable in dealing with perception, either as a criterium of perception or—if one chooses to define perception that way—as perception itself. Thus, in criterium 1 certain reports (i.e. some sort of response) of some

attributes—like sound, smell, taste etc.—are used 1) in their phenomenological sense as indicants of the possible working of a sense modality through the whole perceptual system, or 2) just as responses on the performance level used in a subsequent S-R analysis.

Further it is assumed that a subject is able to distinguish experiences due to stimulation initiated or controlled by the experimentor. This last assumption in fact belongs to the control tasks of the experimentor, but by instruction this control-burden is often loaded on the subject.

The assumptions implicit in criterium 1 are only roughly verified.

Criterium 2 is a physiological one. Here it should be remembered that the knowledge about end-organs some twenty years ago was thought of as being more or less complete—at least by psychologists. What seems to be forgotten is that the knowledge was mostly confined to the anatomy of end-organs. Recent findings, see e.g. Morgan (1951), Mackay (1961), show that end-organs anatomically alike and found in the same sense department may not function in the straight-forward way hitherto believed. This fact seems to hold true for a variety of senses.

Criterium 3 deals with the pathways from the end-organ to the so-called brain. Already the term brain points out that this criterium is a rather loose one. Here the same objections as for criterium 2 apply. The system of pathways is today considered far more complicated than at least psychologists believed some decades ago.

In the late forties a double setup of pathways from the end-organs to central parts were found, viz. a swift direct system of pathways—known to earlier workers—functioning as message channels, and a slow indirect system which appears to serve as a diffuse arouser of certain brain-areas, Hebb (1955), Samuels (1959). Adding the fact that most pathways are crossed at several levels, criterium 3 turns out to be moderately helpful.

Criterium 4 deals with the question of stimulation. It is stated in a form implying that the old Helmholz problem of "what is stimulus?" is a solved one. Criterium 4 is to be seen as Sherrington's concept of the "adequate" stimulus for a receptor. It must not,

naturally, be confused with the Johannes Müller notion of specific energy of nerves from the 1820's where energy is used in a more diffuse "physic" sense. (The notion of specific energy of nerves belongs to criteria 1 and 2. What Müller did was to carry the anatomical idea of separate sensory pathways beyond the proven facts, giving a hypothetical anatomic explanation for the unique qualities of experience.)

The term energy in criterium 4 stands for measurable attributes of physical systems—i.e. the energy and not the source of energy, and the criterium refers to typical or module classes of energy like attributes of light, soundwaves, mechanical distortion etc. Thus, we distinguish stimulation from excitation and, as we are dealing with the definition of sense modalities—i.e. groups of end-organs—we talk about stimulation of these modalities (which is probably different from the stimulation of a single cell). The problem is that all groups of end-organs do respond to more than one type of energy. Electrical stimulation e.g. seems to be adequate for every type of end-organ.

To further complicate the picture, different usages of the term sense modality can be found.

Waren (1934) defines the term as Modality: a separate sense or department of sense.

Wenger, Jones and Jones (1956) follow this definition and say:

> Modalities (sing. modality): Refers, in this sense, to a sense department, i.e. a sense, such as touch, vision etc.

Drever (1952) in his phychological dictionary has the following to say:

> Modality: qualitative attribute or aspect of sense experience as belonging to a specific sense department.

Colleagues of the present author seem to use the term still more loosely by referring to any judgemental aspect or situational attribute to be handled by the subject in an experiment as a modality. One can thus deal with the modalities of velocity, time, weight or length.

We conclude by saying that the definitions of sense modality

are floating and in all instances rather vague. They have been used to categorize the conventional sense departments. As a result of this definition confusion, the number of separate senses vary in number from some eight or ten up to fifteen or more.

Obviously the varying number has to do with the degree of simplification and how the criteria are used. In the longer lists vision is thus regarded as being built up by several senses, e.g. modern neurophysiological theories of color vision.

The sense modalities are composed of several end-organs, identical or more or less equal, within a modality and because of the numerousness of the end-organs, distributed over a certain area of the organism. Probably other not explicitly stated classification principles have been, or are being used in this categorization of sense departments.

Anyhow, keeping in mind certain reservations, we end up with all of perception as instances of sensory interaction. This is exactly what we started out to avoid and some other strategy must be employed.

2.4 *Sense modality redefined*

From the above discussion it is clear that the originally strict concept of sense modality must be viewed with caution. One reason for this is that recent research has shown that the criteria used in the traditional definition cannot be applied rigorously. For the time being then I will accept a loose definition of the concept.

Let me define it thus:

Sense Modality (sense) here refers to the conventionally isolated sense departments such as vision and audition as well as to commonly isolated substructures of these senses such as color vision, photopic and scotopic vision. Such senses or substructures of senses are roughly definable by the four criteria used in the traditional definition.

Sense modality thus defined only implies that I accept the conventionally isolated sense departments without worrying too

much about the criteria underlying the definition. This further implies that I recognize that any definition of the concept of sensory interaction, as long as it is dependent on the concept of sense modality, will be subject to the same vagueness.

2.5 *An initial definition of sensory interaction*

As a point of departure I define sensory interaction as interaction of the sense departments. By this is to be understood that a response in a sense organ is changed by stimulation of another or other sense organs with their characteristic stimuli.

It is customary to distinguish between intermodal and intramodal sensory interactions. In the following I shall introduce a further simplification by handling them as one phenomenon. The argument for this runs as follows. If a modality (e.g. vision) is considered to be a group of end-organs with different spatial sites and/or functional tasks, then sensory interaction has been previously studied under such labels as retinal interaction, color conversion, auditive masking, binaural interaction—what is classically called intra-modal interaction. These examples are—on a psychophysical observation level—analogous to studies where the stimulus energy is also varied quantitatively, i.e. inter-modal sensory interaction. Observe that the split into intra-modal and intermodal interaction has to do with the traditional modality definition. There it is said that a specific energy *or* range of energies should be proven to constitute the stimulus for the unique experience. Keeping this in mind it seems natural not to distinguish intra- or inter-modal interactions as qualitatively separate phenomena. Also worthy of note at this point (to be dealt with more extensively later) is the fact that many of the experiences through which a sensory interaction may manifest itself do not appear to be of the sense-bound type called "unique" in criterium 1—one example is the experience of time.

By *sensory interaction* I mean that a permanent or temporary change in response to a given stimulation occurs when a *new* stimulus component is added. This new component may stimulate either the same sense organ or a different one. This new stimulus-

component will be denoted by the terms *accessory stimulation* or *auxiliary stimulation.*

By putting the topic of interest in this form I have stumbled on a new type of difficulty. The accessory stimulation may function in two ways, it may either be 1) presented (and perceived) as part of the stimulus content or 2) presented (and referred to) as the stimulus background against which the stimulus is perceived. Sensory interaction can occur with both modes of presentation and may show differential effects depending on whether the effects are of a "pure" sensory character or of a more cognitive or judgemental nature. This is a problem which will be discussed further in the sections dealing with the author's own experimental work.

It may be noticed that nothing has been said as yet about the temporal relations between the accessory stimulation and those already existing. Two types of approach can be distinguished here.

A. In some situations the accessory stimulation is produced temporally before the presentation of the ground stimulus. This kind of variation obviously can be handled in at least two ways. One depends on the fact that sometimes the effects of stimulus events last longer than the duration of the events themselves. Stimuli are said to leave "traces" or "engrams" of themselves. This point will be elaborated further in the next chapter. The other is dealing with the accessory stimulus components as prewarning signals—when there is a temporal lag between the accessory and the basic stimuli. This type of manipulation immediately brings up the term attention. I will attend to that in the next chapter as well.

B. The other line of approach deals with simultaneously applied accessory and original stimuli. This is naturally to be seen as an alternative way of studying contextual influences of intra- and inter-modal character but the situation is also typical of attention experiments. Take a simple example: a subject is presented with simultaneous visual and auditive stimulation and performs a visual task. This setup immediately suggests that the auditive stimulation serves a disturbing function—it functions as noise. Noise is something that regularly affects a subject's per-

formance, either because of changes in the subject's attention or because of other factors. As said under A. the concept of attention will be further discussed in the next chapter.

Even if both approaches outlined under A and B could be called sensory interaction I will confine myself in the following, to the second approach; viz. *simultaneously applied accessory and original stimulation.* As indicated, there is a certain overlap between the concepts of sensory interaction and attention. This overlap will be further discussed in the next chapter. Here it is sufficient to say that the concepts do differ from each other. Attention is most often used as referring to non-sensory activity, as in Hebb (1948), while sensory interaction is defined in stimulus terms and thus more tightly bound to an experimental setup and therefore easier to analyse in S.O.R. terms. By keeping one's eyes open to the possibility of sensory interaction effects when working with different kinds of simultaneous stimulation it may be possible to tie certain attentional effects to stimulation and a specified sense modality channel, thus showing that some non-sensory activity is sensory after all.

Chapter 3

Some concepts relevant for the effects of sensory interaction

3.1 *Introduction*

In the previous chapter a set of arguments were given, mainly concerning definitional aspects, for using the concept of sense modality with caution. Also given was a tentative interpretation of the concept and from this point of departure, initial steps were taken in forming a meaningful conception of the terms sensory interaction or sensory interrelation.

At the end of the last chapter the concept of attention was mentioned in connection with its relation to and implication for the present problem.

The topic of interrelations of the sensory systems in perception has many ramifications, one of which, as shown, concerns attention. Other aspects lead us into problems of learning, sensory-motor phenomena, adaptation, synesthetic phenomena, contextual effects like contrast effects, after-effects, temporal effects and problems of work and energy expenditure, to name but a few. As our problem is one of exclusion and limited to a narrow field of study, we will deliberately omit related topics from the next chapter onwards, only including references when they are necessary for the discussion.

If I expand on some of the ramifications indicated above I eventually end up with general theories of perception. Since the scope of the present work is of necessity restricted we will also try to keep these general theories of perception at a minimum.

3.2 *Four concepts related to sensory interaction*

Four central concepts in general theories of perception will play a more central role: a) attention, b) learning, c) sensory–motor activity and, d) adaptation.

Without arguing the question at present of whether the words attention, learning, sensory–motor activity and adaptation are labels, intervening variables or something else, the four fields will be reviewed in order to place each of these concepts in relation to the present study.

3.3 *Attention*

Without indulging in a deeper discussion of the concept of attention, something must be said in order to indicate its possible application for the problem of sensory interaction. Gibson (1941), Hebb (1948), and Broadbent and Gregory (1964), among others, have dealt with the concept of attention—or rather with the group of concepts in the attention family—more extensively, and it might be convenient to take their discussions as a background. The first two authors observe that the notions of attention, set, attitude, expectancy, hypothesis, intention, vector, need etc. have one common element. They all recognize that responses are determined by something else besides the immediately preceding sensory stimulation. Hebb uses *non-sensory activity* as a collective term. It is further noticed that these terms for attention are a reference to a central process and Hebb further proposes that this process is *relatively* (my italics) *independent of afferent stimuli*. (A somewhat different position is taken by Hebb (1955) where afferent stimuli are recognized as having an effect over and above their cue function.)

Let us try to explicate—in a very rough way—some aspects of attention. Attention in current scientific usage has many meanings. It could refer to a) the final result of attending as measured by scientific methods; b) the phenomenological Prägnanz of the attended phenomenon; c) the adjustment of the receptors in this process; d) the intensity of the process or, e) the hypothetical activity which produces the intensity, f) the selectivity in the process and, g) the hypothetical activity which produces the

selectivity; h) animistic undefinable attributes of the organism. I have chosen to treat e) and g) together here and call this attention.

Regard it for the sake of convenience as an intervening variable. It is then convenient to distinguish two attributes of attention as:

A. the intensity of attention, d)
B. the direction of attention, f).

These two attributes are manifested in quite different ways in psychological experiments. (See (a) above.) The intensity of attention is dealt with both in perception experiments and learning experiments.

In perception experiments the change of intensity of attention may manifest itself as

1) the amplitude of a response
2) the veridicality or the efficiency of a response
3) the latency with which a response is delivered
4) the satiation and fatigue of a response.

If we go back and look at our provisional definition of sensory interaction in chapter 2, we find that interaction effects will turn up as 1), 2), 3), or 4), which means that we will stumble upon difficulties in keeping attentional effects and sensory interaction effects apart. It may alternatively mean that some of the effects "explained" as attentional may be linked to stimulation.

In learning experiments—here considered a side line for the present—attentional effects are naturally indicated by the ability to recall the stimulation and by resistance to extinction.

As regards the *direction* of attention one notices that it is appearing in general as selectivity directed towards the stimulation. This change in selectivity can appear more specifically as

1) the decreasing or increasing of thresholds (absolute or differential). If thresholds are changed, then subjective supra-threshold scale-values may be affected.
2) a variation in which stimuli or stimulus-components are effective in forming the organism's responses out of the mass of stimuli present at a given moment.

As in the case of intensity of attention we find that direction also yields effects which are of the same type as those to be expected from sensory interaction.

3.4 *Learning*

3.4.1 *A background*

Learning in perception is constituted by two separate questions. One is the traditional question if perceptual organization and development is learned or not. The other one may be put in this way: is perception, innate or not, modifiable by learning? It is this last question which has bearing for the present study.

Two things must be remembered. One is that the nativist-empiricist problem is traditionally intermingled with the question of whether perception—innate or not—could be modified by learning. Excluding the nativist-empiricist issue the remaining problem of learning in perception is univocally answered in the affirmative. The trouble that remains—and it is a big one—consists of choosing a definite operational meaning of the term learning as to be found in perception. Elinor Gibson (1963) in an excellent review has shown the almost total confusion of terms in this field. Confronted with this state of affairs one can choose between several ways out. One can regard the problem as solved and leave the term learning undefined. For the sake of practical experimentation this is a safe way in that the problem is transformed into an ad hoc one. This generally accepted solution does not tempt me for two reasons. This study will stand isolated and errors or overinterpretations by empty concepts are bound to be the final result. A more plausible solution is to give my own version of learning as a general, epistemic definition in verbal form. This is then later to be translated into a semi-operational form in the actual experiments. By semi-operational definition is meant what Marx (1951) has called an E/C type of intervening variable which stands for whatever intervening function must be assumed to account for the experimental-control differences observed in the actual experiment.

3.4.2 *The role of learning in perception*

The role assigned to learning is an important one in current discussion of perceptual theory. Several books, articles and reviews have dealt extensively with the question. Some are, as pointed out, extreme advocates for learning as the ultimate explanation of perceptual organization, others seem to doubt the dominant role played by learning and still others are vacillating somewhere in between. A good survey is given in Koch (1959). Common to the first two groups of theorists is the tendency to focus on the rather secondary question of what learning in perception really is. They are apt to speculate in neurophysiological terms or in hypothetical constructs to get a fresh start and pin down the essentials of perception. Central concepts like perception, adaptation and sensory-motor activity are most often left undefined and one is free to infiltrate meanings of one's own into the texts. The need for clarification in this area is great. One trouble is that terms like e.g. perception is used in a double sense. On the one hand it stands for socially important processes within the organism behaving in a meaningful world, on the other hand perception is almost solely studied in relatively neutral and meaningless situations. (An exception to this tradition is Brunswick.) Even Gestalt laws—said to be independent to any meaning—break down in a natural setting.

The main difficulty seems to lie in the fact that the basic organizational mechanisms of behaviour are not known or even attainable with the general terminology of learning. How can we learn to see, if we must see in order to learn; is the classical unsolved question. The concept of learning (often interchangeable with terms such as adaptation, habituation or adjustment) is in most cases applied to perception as if this basis was known. Here the innate-learning issue begins to bother us again. Specially weak points in learning discussions in relation to perception are a) the role assumed to be played by the cortex, b) the strong emphasis on the ambiguous (often mentalistic) concept of reinforcement and c) the hinted idea that simple reactions are sequentially chained into larger complexes. As for the role of the cortex,

it has been shown [Culler and Mettler (1934), Wing and Smith (1942)] that almost all phenomena of conditioning could be demonstrated in organisms with most of the cortex destroyed. The reinforcement issue cannot be treated on the same model as the phenomena of imprinting. In many perceptual learning tasks, e.g. practice effects on geometrical illusions [Köhler and Fishback (1950 a), (1950 b), Brown (1953)] or distorted vision experiments Wooster (1923), Taylor (1962), it turns out that the effects are completely independent of knowledge of results or even knowledge of that an illusion or distortion of vision is being produced. The idea that sensory-motor feedback should act as reinforcement is far from conclusively proven (Smith and Smith (1962). The chaining idea is incompatible with what is known about the learning of perceptual-motor skills.

The reader is reminded that I am not out for a new and better alternative to learning but merely to scrutinize the learning issue in relation to my own studies of sensory interaction.

Hebb (1949) is one of the extreme advocates of learning. He is not primarily concerned with phenomenal facts in perception but rather with relating or explaining the response to stimulation. As the distinction between response and phenomenal perception is traditionally vague within perception theories I will use the word perception for Hebb's response. He is relying heavily on the monograph by Senden (1932) and an experiment by Riesen (1949) in his argument for the role played by learning and past experience in apparently "automatic" perceptual experiences. Senden's monograph dealt with the adjustment of operated congenitally blind persons to a visible world and Riesen reported similar findings from an experiment with a chimpanzee reared in darkness. Hebb's use of Senden's data has been criticized by e.g. Wertheimer (1951) and in the case of Riesen's experiment it was shown [Dember (1960)] that destruction of the retina had occurred during the dark-reared period. Anyhow, Hebb's point concerning the role played by learning (in some form) in the acquirement of what he calls figural identity has been supported by other observations from Helmholz in the 1850's [see Smith and Smith (1962)] up to Riesen (1950) and Walk, Gibson and

Tighe (1957). It is further supported by clinical findings of perceptual completions in cases of hemianopia and different types of scotomata.

To the last two statements above reservations have been made. One group concerns Hebb's concept of figural identity [Dember (ibid.)], another the experiments utilizing an abnormal environment Smith and Smith (1962), Tallarico and Farrell (1964) and a third group the findings of perceptual completions, Cronholm (1951) Teuber (1960).

Another problem is the question of whether the learning or adjustment observed in these studies is comparable to that studied in conventional learning experiments and what the relation is between this perceptual type of learning and the physiological phenomena of adaptation. I will take up the last point in section 3 of this chapter.

If we disregard Hebb's theoretical speculations we could compare these findings with those from studies employing different kinds of distorted vision. The advocates of this method maintain that it simulates perceptual development and that the innate-learning issue can be settled by using these methods. Not being convinced that this holds true, and being interested in the modifiability of perception as such, I can still illustrate some points citing such studies.

Taylor (1962) has performed a series of Kohler-inspired (or rather Stratton-inspired) experiments on distorted vision. He used left-right reversing spectacles, prismatic-spectacles curving the visible world and contact-lenses with built in prisms. The main findings from our point of view is that adjustment or learning is not complete in the traditionally expected manner. It appears only to function within relatively independent subsystems, all involving retinal stimulation but including different sensory and motor components from other modalities. Transfer between these subsystems appear to be negligible. Thus, training within one subsystem—e.g. hand-eye coordination—does not produce adjustment within another subsystem—like eye-knee coordination. The subsystems seem to function relatively indepen-

dent of each other and adjustment over several subsystems only take place when several sensory modalities participate in the task.

Wallach et al. (1963 a), (1963 b) have arrived at somewhat different results in experiments using wedge-prisms (altering the direction in which objects are seen) and telestereoscopic arrangements. Both procedures gave quick adaptation effects—measurable within 10 minutes. With the wedge prism experiment, the effects were obtained also with passive subjects, i.e. subjects just lying down looking at the environment. In the telestereoscopic arrangement certain transfer effects were found. It was not however, transfer between subsystems but between different stimulus figures used in training and test.

The big difference between Taylor and Wallach is that while the former gives his reports in diary form stressing Kohler's "inner" aspects of perception in an every-day-life situation, Wallach performed strict experimentation using standardized and simple tests of the degree of adaptation (learning).

The findings of Mikaelian and Held (1964), and Mikaelian and Freedman (1963), suggest that the contradicting result may not be a function of the scoring technique used, but rather of the degree of difficulty in the reactions chosen as dependent variables.

The same observation is also to be found in Smith and Smith (ibid.). Their book contains a thorough survey of experiments on distorted vision. They start with a review of the works of Helmholz, Stratton, Wooster, Brown, Cox, Ewert, Siipola and Peterson and Peterson. They conclude their critical survey by stating: "The results /from these investigations/ suggest rather conclusively that adaptation to displaced vision involves the learning of highly specific responses, and that the general perceptual adaptation (i.e. learning) which most investigators have sought for cannot be achieved independently."

This seems to be quite in line with the findings of Taylor cited earlier. So far three points relevant for our own study are clear:

1. Perception is to some extent modifiable through practice.
2. This modification may occur through the participation of several modalities.

3. Learning is not the sole explanation of modifications of perception.

The experiments of Kohler (and Erismann) give further evidence for this belief, (Kohler 1951). Although Kohler himself is an extreme believer in learning, his experiments are not quite convincing. In no case is adaptation complete. No matter how long the subjects wore the distorting glasses they never corrected for e.g. reversal in depth cues.

In line with the previous discussion, it was found that the overcoming of the effects of wearing prisms began with cutaneous probing, not with vision, cf. Wallach et al. (1963 a). It is further noticed that perceptual relationships were seen correctly when touch and kinestesis dominated but when vision dominated the relations continued to be reversed. This is exemplified by the constant reversal in depth cues mentioned above.

Smith and Smith cite a series of animal experiments showing the same effects. Prism-distortion used on rhesus-monkeys showed little learning and only specific responses were learned. If chickens were used in the same task no improvement in pecking ability was found.

Smith and Smith (ibid. p. 85) observe that "although learning is the mediating circumstance for whatever adaptation does occur to visual displacement it cannot be considered the primary organizing process of perception . . ."

Also reported in Smith and Smith are some studies concerning anatomical displacement of sensory feedback. Thus, experiments were conducted on the fly Eristalis in which the eyes were rotated 180°. When a normal fly was placed in a drum with striped walls rotating in one direction the fly tended to move in the same direction. With the eyes rotated 180°, the fly tended to move in the opposite direction. Experience did not alter the behavior. Similar findings were obtained using fish with rotated eyes.

In another experiment amphibians were used and afferent or efferent inputs were interchanged. The amphibians did not, as believed previously, learn to correct for these anatomical displacements. The same findings were obtained using amphibian embryos.

Prior to the onset of vision they had their eyes rotated 180° or the eyes interchanged and this led to disorientation of vision persisting throughout the animals life. Experiments where crossing of the sensory nerves to the right and left hind feet of the rat or interchanging flaps of skin from the back of frogs, was accomplished, gave similar results. These experiments all show that spatially organized behavior is not at all affected by experience in lower animals.

We may conclude this part by citing parts of the summary of Smith and Smith (ibid. p. 124).

"Perceptual adaptation in inversion-reversal studies was partial, variable, incomplete and dependent on motor adaptation in specific situations."

Observe that motor adaptation involves gross heteromodal interaction.

"Adaptation to displaced vision was not affected significantly by lack of knowledge of the conditions. Adaptation is apparently selfregulatory, motivated by the imposed non-correspondence between vision and motion."

"Although subhuman primate adapted fairly well to visual inversion, adaptation has never been observed in any other lower animal." Comparing the learning and neurological interpretations of the phenomena of displaced vision, one may conclude that learning is inadequate for giving a complete explanation, while neurological interpretations stress that these phenomena are primarily genetically determined in man and animals.

Smith and Smith's own experiments constitute another body of evidence now to be considered.

Their first series of experiments were done using a fixed mounted prism providing an undistorted inverted visual field of 50 to 60 degrees wide and almost unaffected by movements of the subject. In three experiments subjects performed drawing and writing tasks under one of three conditions, 12 hours continuous performing, half an hour per day for 20 days or pretraining for half an hour for 5 days with inverted reading. It was shown that adaptation with intermittent exposure was equivalent to adaptation with continuous exposure. The degree of final adaptation depended on

the type and complexity of the task. Pretraining with inverted reading had no effect on subsequent training in inverted writing. These findings fall neatly in line with the ones previously referred to.

Smith and Smith then report a series of experiments performed with an ingenious closed-circuit television system allowing multi-dimensional variation of the different factors involved in space perception. Although their own interest mainly concerns the interaction between perception and body motion, many of their experiments have relevance for our problem.

Thus, their studies of the effects of different degrees of displacement of vision show that there is a range of displacement within which normal perceptual-motor activity can be carried out or be adapted to, but that beyond this range break-down occurs. The point where break-down occurs varies with the tasks and activity involved, but the main thing is *that little or no learning appears outside a certain range of distortion.*

For our problem of sensory interaction this lengthy review implies the following. Disregarding the question of whether sensory interaction is learned or not, we must bear in mind that learning or adaptation may affect sensory interaction effects even during a short period of time such as an experimental session. The studies mentioned above make it possible that the specific reactions to be studied—e.g. judgement of velocity in a bimodal setup—should be readily readaptable to the orginal level, i.e. that prevailing without any auxiliary stimulation, motivated by e.g. a noncorrespondence in stimulation over different modalities.

Another point worthy of note is the generally stated importance of sensory-motor activity for perception and learning in perception. Here again the confusion of terms within these areas is evident. In the references given, in no instance has an attempt been made to define perception. Let me resign on this point while indicating that the review is somewhat ambiguous in that I may have falsely imposed my own notion of perception (from chapter 2) on all the studies dealt with. The same holds for learning and adaptation. My own vague position will be repeated thus:

The term learning as discussed above could stand for 1) the

process within the subject inferred from 2) the antecedent stimuli-variables, 3) the instructions given to the subject and 4) the subject's reactions as observed or measured. In this text we refer the whole time to 1) treating learning as an hypothetical construct and errors in citations may be excused.

3.4.3 *Summary*

The experiments in which no or very little learning was inferred were characterized by some or all of the following features:

a) employed lower animals
b) employed immature organisms
c) used severe distortion of stimulation
d) hindered or restricted action
e) hindered or restricted the simultaneous working of several modalities
f) employed severe deprivation of stimulation in early development.

Each of the features a), b) and c) seems to be sufficient by itself to make learning impossible. The necessary features are unknown. It is unclear whether each of the features d), e) and f) is sufficient by itself to make learning impossible.

The experiments in which learning was inferred can be characterized thus:

a) employed humans or higher primates
b) employed mature organisms
c) used moderate distortion of stimulation
d) allowed some probing or action
e) restricted and hindered the simultaneous working of several modalities only moderately
f) moderate deprivation of stimulation during maturation.

The question of sufficiency and necessity of conditions is less clear in these experiments, as the learning effects observed may be interpreted to some extent in terms of concepts other than learning. The type of effect found is apparently independent of the traditional reinforcing state of affairs.

Our inferred learning process is thus tied in a general way to a group of antecedent variables. On the dependent variable side it is naturally tied to observed changes in perception and perceptual behaviour, usually measured as successive differences between experimental and control conditions or as successive changes back to a preadaptation level.

Partly due to its apparent independence of reinforcement, this type of learning is often treated as adaptation although it is unclear whether adaptation is used as implying changes at a peripheral level (i.e. like dark-adaptation) or refers to some more diffuse central adaptive process—where adaptive is used as a descriptive or denotative term to indicate change toward some assumed homeostatic level. This point will be taken up in section 3 of this chapter.

3.5 *Sensory-motor activity*

3.5.1 *Background*

The idea of the dependence of perception upon motor action patterns or sensory-motor interrelations is an old one. It occurs in the writings of Hughling Jackson, Mach, Münsterberg and Langfeld, to mention a few. Sensory-motor interaction is not really a separate phenomenon from sensory-interaction, but traditionally it has been treated as a separate field of research. I will do likewise but stress that the two problems are to a large extent identical.

The fact that sensory stimulation has an effect on e.g. muscular tonus has been shown by numerous physiologists from Sherrington onwards. In the previous section it was shown that sensory-motor interaction was used as an explanatory concept by e.g. Taylor, Smith and Smith and Kohler.

The idea that any percept is determined by the interaction of sensory and motor activity is basic in the Werner and Wapner theory (1952) but the same thoughts could be found in Hebb (1949 and 1959) integrated in his key conception of the cell assembly. Hebb (1959) says that "most assemblies would be established during the occurrence of particular motor activities . . . each would

therefore establish neural connections with and tend to produce, its own motor activity."

The same holds true for Gibson (1950 and 1959). His key hypotheses of ordinal stimulation—spatial as well as temporal—appear in essence to say the same thing as do Werner and Wapner and Hebb. The difference is one of theoretical focussing in choosing their explanatory concepts, not one of denying the integrative working of the perceptual system. This last point is more or less explicitly postulated by them all. This state of affairs leads us to refrain from indulging in theoretical evaluations here, as was earlier done in the case of learning.

3.5.2 *Empirical findings*

Instead of further discussion I will present some empirical findings to illustrate the effects. A large group of experiments done on sensory-motor interaction deal with the perceiving of the phenomenal upright. Gibson (1952) describes the different methods employed by workers from Wertheimer and Mach up to himself, Mowrer and Witkin. The problem according to Gibson should concern itself with how different modes of stimulation interact in normal perceiving and when some of the modes of stimulation are in conflict. The main findings are that interaction does occur and that stimuli do function as cues or clues when they are contradictory. The stability of a normal experience of the upright and when the head is e.g. inclined to one side is described by Gibson thus: "In the case of reciprocal visual-proprioceptive stimulation, the coupled variables continue to form an invariant resultant which is in correspondence with the objective direction of gravity and which provides the stimulus for a univocal impression of the vertical. This is why the ordinary visual scene continues to look upright when one inclines his head and thereby rotates his retinal image." In the case of conflicting cues the variables acting do not yield an invariant. The values do not correspond in the regular fashion and the resulting perception is ambiguous. The subject perceives different verticals through different modes of stimulation and is forced to choose between them. With such an unstable

perception it is probable that subjects will differ from each other in their resultant perception as Witkin and Wapner (1950) and Witkin et al. (1954) have observed.

Werner and Wapner (1952) summarise a series of their own investigations of the perceived upright during body tilt, accessory electrical stimulation of neck muscles, varying starting position and individual equilibrium. A theoretical postulate of Werner and Wapner which receives empirical support is that different sources of stimulation may substitute or compensate for each other. If one mode of stimulation is missing, the subjects compensate with others, thus sometimes giving nonveridical judgements. This is the Gibson observation of contradictory stimuli functioning as cues.

Noble (1949), Mann, Berey and Danterive (1949) and Passey (1950) report similar findings as do also Witkin (1953 and 1954), Wapner and Witkin (1950 a and b), Bauermeister, Werner and Wapner (1964). Chandler (1961) got similar effects by stimulating monaurally with a tone of varying loudness.

According to the Werner and Wapner theory, the essential factor in perceiving the subjective upright is the degree of muscular involvement aroused by different modes of stimulation and serving as an interacting stimulus-component for the perception of the vertical.

Corso (1962) found that bodily position also affects the absolute auditory threshold.

Kohler (1956) in his now well-known experiment with blue-yellow spectacles furnishes another type of evidence for the role of mediating motor activity. The subjects wore spectacles which, to each eye, admitted blue light through the right half and yellow light through the left half. After a long period of wearing the glasses, the subjects were said to be adapted to the visible world perceiving it "normally". When the glasses were removed the subjects saw gray objects as yellow when they fixated them to the left and as blue when they fixated them to the right irrespective of that the same retinal areas were stimulated in each case. However, just looking to the right gave a yellowish hue to objects and looking to the left gave a bluish hue, i.e. after effects of adapta-

tion. Similar effects have been observed after wearing prismatic spectacles (ibid.) and putting on and taking off a prothese, Henderson and Smyth (1948). The tactile feel of the empty frames or the feel of the prothese cut off the after-effects of adaptation. Sensory conditioning or not, these findings indicate sensory interaction via motor activity. The direction of the interactive effects are, however, seldom as univocal as Kohler suggests; see e.g. Lunn (1948).

A further point may be made here concerning the so-called sensory conditioning serving as an explanatory concept in these observations. After wearing prismatic spectacles a different amount of curvature of straight lines is experienced when the eyes are turned to one side than when they are turned to the other. Gibson (1959) remarks that this need not to be viewed as an instance of sensory conditioning but "in fact this situation in reverse was what confronted the eye as it explored the optic array behind the prism during the adaptation period." Gibson's remark, however, does not explain the findings of the experiments dealing with the restoring of the adaptive after-effects.

3.5.3 *Summary*

We may conclude this section by saying that the different findings are so far not univocally explainable by any known unitary theoretical concept or accepted mechanism. Neither adaptation nor learning can be used solely as explanatory concepts.

Experiments on sensory-motor interaction do, however, show that the boundaries between different sense modalities are not as sharp as usually believed. The interdependence of sensory and motor systems is proved but the rules for this interdependence must be sought for by further exploratory experimentation.

3.6 *Adaptation*

3.6.1 *General discussion*

This section, trying to relate the phenomenon of sensory adaptation to my problem will begin with a clarification of the term

adaptation. As a background see e.g. Helson (1964), p. 36. As noticed in the sections 1 and 2 dealing with learning and sensory motor activity an ambiguity in the usage of the term exists. Sensory adaptation is usually arbitrarily treated separately from learning because it does not fit in with our prejudiced ideas of learning. In connection with perception this prejudice does not put up any barriers, but it certainly does not solve any problems either. I will use the word adaptation here as an inferred process within the organism, i.e. as an intervening variable or a hypothetical construct. Thus, the process of adaptation is distinguished from the end result. In this sense at least five different denotative meanings of the term can be isolated:

1. The same process as that inferred by the word learning.
2. The process of becoming more effectively adjusted to conditions involved in learning or work (sometimes called habituation).
3. The inferred process resulting in progressive change in responses with continued stimulation. ("Continued" does not necessarily imply continuous stimulation.)
4. The process resulting in a decrease in response to a stimulus, due to attending to something else (sometimes denoted attentional adaptation).
5. Effect produced on sense organs by continuous and unvarying stimulation so that ultimately no sensation is experienced at all (sometimes referred to as accomodation).

Apart from the five meanings listed above, adaptation in common scientific language is frequently confused with or used as a synonym for adjustment, satiation, enhancement, inhibition, facilitation, adaptation-level, contrast, fatigue and compensation to mention a few examples. I will, however, overlook that state of affairs and return to our list of five meanings. As a physiological model anchored by strict operational experimentation, adaptation has the meaning given in point 3) above. At first glance this also seems to be the commonly accepted meaning. As a matter of fact, an amorphous body of empirical facts are treated as adaptation because of the general tendency of various factors to yield ana-

logous effects to that of adaptation, i.e. change of response. Adaptation is used as an explanatory device in a variety of situations bearing a very loose resemblance to each other.

If I use adaptation in accordance with point 3), regarding it as a process resulting in progressive change in responses with continued stimulation I refrain from asking the question whether the other meanings deal with identical or similar processes or not. It is sufficient to say that empirical facts dealt with under the heading of adaptation are ambiguous and hard to interpret.

The interest for adaptation among psychologists may be connected with the principle of homeostasis also borrowed from physiology and also thought to be a relevant explanatory principle in psychology. All phenomena discussed in relation to adaptation are also to be found under the homeostasis label. The principle of homeostasis states in short that the organism has a tendency for compensatory adjustments to distractions. One of the processes trying to maintain this work level or equilibrium is called adaptation. In psychology homeostasis is most often postulated. Psychologists utilizing adaptation in this way are e.g. Gibson in his work on after-effects of adaptation and Kohler in his discussion of the zero-point established by the "stimulus milieu."

In Köhler's work the homeostasis concept does not enter, see e.g. Prentice (1959). Instead, the concept of isomorphism serves the same function and leads to neurophysiological model making. Köhler has devoted a long series of experiments and theoretical work to adaption phenomena. His satiation concept is to a large extent analogous to adaptation as it is used here. Parallel with the work of Gibson (1933) on adaptation and after effects, Köhler concluded from his work with reversible figures, that some process of satiation operated on specific figural organizations to make them weaker and unable to stand competition from alternative organizations. A row of experiments with simple line patterns finally led up to the theory of the brain as a potential volume conductor. The main empirical results of Köhler's experiments are in short that a standard stimulus produces a different response after adaptation (satiation) of the organism than before. Köhler explains this in terms of field concepts (i.e. taking into account

the whole visual field and seeking laws of interaction between stimuli factors) and changes of electrical polarization in the organism's brain.

Gibson (1959) treats sensory adaptation in a different way. Whereas Köhler started with the figure-ground phenomenon as a basis, Gibson searches for stimulus variables: "mathematical variables with which to analyze visual organization." Earlier and later stimulation should be treated as one, states Gibson. Stimulation is always both a flow and an array. Some receptors (e.g. in the ear) respond only to changes in stimulus energy. Thus, changes in stimulus-patterns are stimuli and these need not to be continuous (e.g. stroboscopic motion). Unchanging stimulation to some receptors (not all) changes experience to a neutral—zero—quality. (In the list in the beginning of this chapter, point 5: accomodation.) The phenomenon consists of "a shift of correspondence between a dimension of stimulation and a variable of experience." The so-called negative after-effect thus represents a readaptation to stimulation prevailing before the beginning of the experiment. The same reasoning also holds for perception of objects and space. Gibson handles Ivo Kohler's experiments in the Kohler spirit and states that they fit well into this way of seeing the problem. He hints that the classical modalities of sense give way to this type of adaptive process. Citing Woodworth he says in a similar connection, "perhaps the organism has a need to see clearly, hear distinctly and feel exactly." Gibson thus seems to build his notion of adaptation on some axiomatic ideas of utility and homeostasis.

Adaptation for Gibson includes learning and is "a shift of psychophysical correspondence such that a persistent value of stimulation tends to be that which evokes normal quality of perception." According to Gibson, Köhler's figural after-effects are not adaptation as, although they depend on prior stimulation, they cannot be accounted for by a shift in psychophysical correspondence of a *dimension* of perceptual experience. He distinguishes between the antecedents of adaptation and adaptation per se and states somewhat cryptically that sensory adaptation is confined to one dimension. The exact meaning of the word dimension is hard to get at. Gibson tells us that this theory is strictly dimensional

or psychophysical in contrast to Köhler or Helson who prefer to believe in an automatic sensory organization. Dimension here has some undefined meaning. Even assuming that it stands for the qualitative attribute judged his argument is still hard to follow. In the case of taste where it has been shown that adaptation to e.g. sweet changes experience for other taste qualities and also that adaptation to a certain temperature that also changes sensitivity for different tastes. It is hard to see how those instances could be excluded from adaptation because they are not confined to one dimension. Adaptation for Gibson stands for a nonpermanent correspondence between "values" of stimulation and "qualities or intensities" of experience.

From this formula it also follows that there is a permanent correspondence between *differences* in stimulus values and *differences* in perceptual qualities or intensities. This is the fundamental kind of psychophysical correspondence. In this way Gibson could still stick to a pure stimulus explanation of the phenomena of adaptation.

The relation to Helson is given by Gibson (ibid.) thus: "the phenomenal norm /of adaptation/ is analogous to Helson's concept of the adaptation level. But the more radical concept of an alteration as psychophysical correspondence may not be acceptable to Helson."

Here again a comparison by analogy. If Helson's position is scrutinized the comparison turns out to miscredit both authors (see Helson 1964). The main difference lies in the fact that Gibson confines adaptation to sensory processes, which have opposites or which form oppositional series while Helson clearly indicates that all behaviour involves adaptation.

It has been shown that psychophysical experiments can seldom, or never, be performed without considering the impact of past stimulation and serial effects from stimulation encountered during the experiment. Helson's ideas are useful when viewed as a specific theory of frames of reference within psychophysical experimentation. These effects may, however, be handled in a different manner; Eisler and Ottander (1963), Eisler (1963).

3.6.2 *Summary*

As illustrated by the short review above, the concept of adaptation is a very ambiguous one. The meaning is diluted by intensive use of analogies and the operational meaning it has in one experiment is seldom carried over to others. The empirical fact that continued stimulation changes subsequent responses has been conclusively proved. If, however, this change is due to stimulus factors or organismic factors, or both, if it is automatic or learned, if it is sensory or cognitive has been hotly debated. The picture is confused and in consequence my study will strive to obtain operational clarity and will hesitate to use the term adaptation as an explanatory concept.

Chapter 4

Sensory interaction — A survey of experiments employing visual and auditive stimulation

4.1 *Background*

In the introduction to this text Bartley (op. cit. p. 57) was cited as saying "all too little has been done by psychologists and other biologists directly to study sensory interrelations. Their study is the exception rather than the rule." It was proposed that this statement had a definitional basis and did not reflect a lack of interest from the psychologists. The two previous chapters have tried to show some of the definitional difficulties involved and it has been shown that several of the main theorists have in fact dealt with sensory interaction, although in an indirect way.

If one looked for experiments and reviews dealing with experimentation in the field proper, one might gain the same impression as Bartley, but still some good and exhaustive surveys of earlier experimentation can be found. Bartley himself has written some good sections in Bartley (1941 and 1958). Pieron (1952) gives some aspects as does Beardslee and Wertheimer (1958). Dember (1960) devotes a considerable space to the topic, relying mainly on the review by London (1954) on sensory interaction experimentation in the Soviet Union. From a more specific theoretical point of view the matter is discussed in Helson (1964).

The London review—containing about 500 titles—seems to have functioned as a catalyst for a renewed interest in sensory interaction among psychologists. It is, however, erroneous to believe that the Russians are unique in their interest. An old tradition is also to be found in Europe and America. Reviews of earlier work are

given by James (1910), Ryan (1940) and Gilbert (1941). In this survey I will use these references as a background, and in some instances cite second-hand from them.

The experimental originator of sensory interaction studies is said to be Urbantschitsch (1883, 1888 and 1902) a German aurist. In a series of experiments and observations he explored sensory interaction effects among a variety of modalities. James, in his Principles, ties the observations of Urbantschitsch to the general problem of sensation (sensation may be read as perception using modern terminology). James initially gives earlier evidence for the notion that all sense organs influence each other's sensations. Thus, subjective heat increases with the skin area stimulated, heat and touch are confused when the stimulation occurs through a mask on the skin, coloured objects have a chromatic minimum size, objects appear to increase in size when the intensity of the stimulation is increased, subjective weight is changed with the temperature of the object judged and a heavy point moving over the skin goes phenomenally faster than a lighter one of the same speed. Urbantschitsch found that the hue of a colour too distant to be seen, could be recognized immediately when a tuning fork was sounded close to the ear of the subject. The same holds true for the acuity of vision with simultaneous auditory stimulation and reversed for acoustical acuity when lights of various colours served as auxiliary stimulation. Smell, taste, touch and temperature were all found to fluctuate when lights were seen and sounds were heard. As indicated, this is by no means the first observation of sensory interaction. Miscellaneous medical anecdotical reports are found at least from the 17th century. In 1669, an anatomist, Bartholmus, observed that partially deaf people heard better in the light than in the dark. Weber made the observation cited by James about weight and temperature. He found that a thaler placed on the forehead is experienced as heavier when cold as compared to when it is warm (a finding which later experiments have failed to verify).

Although the scattered observations cited above prove nothing for or against sensory interaction they still show that the tradi-

tional view of the sense modalities as isolated unities is not a universally accepted one. A parallel idea is that the sensory modalities work as an organized whole.

4.2 *A classification of sensory interaction experiments*

Several alternative categorizations of sensory interaction phenomena have been proposed. For the sake of simplicity and continuity I will choose the scheme proposed by Ryan (1940). He presents the following table.

Table 1

A Dynamogenic Intersensory effects.

B Intersensory Dependence and Consonance.
   a) similarity of qualifications across modalities
   b) changes in quality due to heteromodal stimulation

C Intermodal Relations in Perceiving Spatial Qualifications.
   a) changes in localization due to heteromodal stimulation
   b) cooperation of modalities in production of spatial qualifications
   c) reorganization of spatial properties under influence of reversal or distorted cues

D Intermodal Relations in Perceiving Other Nonspecific Properties of Objects.

Note that two specific areas are excluded in this classification. One is associative imagery or synesthesia and the other is all types of so-called intramodal phenomena. A considerable part of the experiments to be found under A to D have in fact originated as analogues of intramodal findings. Synesthesia will be disregarded here, it being mentioned only because of its clear relation to the type of problems discussed here. Some intramodal or contextual

phenomena relevant for the dicussion, and for my own problem, will be taken up in a separate section later on.

Table 1 needs some comments. (A) "Dynamogenic" is used to label instances where sensitivity or acuity in one modality is changed by stimulation in another modality. Here absolute and differential threshold measurements are the main methodological techniques. (B) Includes experiments dealing with suprathreshold changes that are not of a differential threshold character. This includes changes in subjective quality and intensity. Both (A) and (B) focus on *specific* qualities, i.e. attributes of objects ordinarily experienced only through one sensory system—what has traditionally been called sensations. In (C) and (D) general, not modality-bound, properties of objects are dealt with. It is specifically this type of phenomena that is hard to find and isolate, as these phenomena are usually treated in conjunction with related problems (e.g. set, noise, time-order-error, etc.).

In the survey of experimental findings given below, experiments without reference dates have been quoted second-hand, mainly from Ryan (1940), Gilbert (1941) and London (1954). Ryan's review includes experiments of the types given in Table 1. Gilbert's study is mainly confined to dynamogenic studies (A) and this also holds true (to a certain extent) for the London review.

London observes that the Russian experiments have been neglected due to language difficulties and to difficulties in duplicating the reported findings. He also makes some reservations on the grounds of inadequate instrumentation and methodology, scanty detail and primitive statistics. For the sake of honesty one is apt to extend these reservations to many of the experiments reported by Ryan and Gilbert. Some caution is thus needed in evaluating the results.

In the survey, I will confine myself mainly to studies employing visual and auditory stimulation. In fact most of the experiments known to me have chosen these modalities but exceptions are to be found. Here, these exceptions are for the most part excluded. In the remaining part of this chapter categories A to D will be discussed and exemplified with typical experiments.

4.3 *Dynamogenic effects*

4.3.1 *Color and brightness sensitivity and auditory sensitivity as studied with psychophysical methods*

Urbantschitsch (1888) has made some observations on this point which are at least suggestive. He found that auditory stimulation with a tuning fork increases absolute colour sensitivity, that binaural stimulation has a greater effect than monaural and that tones of higher pitch are more effective than those of low pitch. Urbantschitsch (1903) observed that different colours are influenced differently by different pitches.

London writes that the Russian experiments reported the same type of findings. Auditory stimulation of moderate intensity seems to increase sensitivity to white light for the dark-adapted eye. As regards monochromatic light it is found that the effect varies with wave-length. Thus, sensitivity to blue-green is increased but decreased for orange-red. It is unchanged for yellow. The degree of effect is said to vary directly with the intensity and duration of the auxiliary auditive stimulation. The opposed character of colour sensitivity to green and red found with auxiliary auditive stimulation was also found, e.g. with the head tilted backward. (Compare the Werner and Wapner sensory-tonic theory mentioned in Chapter 3.) In this condition, however, the effects are reversed, blue-green sensitivity is decreased (up to 25 % of the original threshold value) and orange-red sometimes increased. (Temperature and gustatory accessory stimulation is said to show the same effects as auditory stimulation, including the lack of effect in the case of yellow!)

The same opposed character of green and red has also been shown with direct electrical stimulation of the eye. Where anodal eye contact was used, sensitivity for green-blue was increased and decreased for orange-red. With cathodal contact the effects were reversed. This finding hints at a parallel of auditory stimulation with head-tilt.

In a strict physiological experiment Horn (1963) showed that signals evoked by someaesthetic and photic stimuli interact in the visual pathways of cats. Acoustic stimuli were shown to modify

visual response in rabbits in the striate cortex, Lömo and Mollica (1962), and response on electrical shocks applied to the optic chiasma in cats, Dumont and Dell (1958).

London reports that pronounced effects on peripheral visual sensitivity have been demonstrated following auditory stimulation. Peripheral sensitivity decreases on exposure to sounds of average or higher intensity. The sound of an aeroplane motor is said to drop the sensitivity 20 % of the original value. Exposure of ultrasonic frequencies (32,800 cps) have, however, been reported to increase peripheral sensitivity. Other instances of heightened sensitivity are also reported, but are sometimes attributed to an abnormal physiological state of the subject. The results are puzzling and one is apt to suspect that several types of effect are involved, e.g. when sound is perceived as tone or noise, or as part of a figure or as belonging to the background.

A more general finding from the Russian experiments is a two-phase sequence of initial decrease and later increase of peripheral sensitivity. This is also reported for macular illumination as the auxiliary stimulus and for ultrasonic frequencies.

An experiment yielding contradictory results is reported by Maruyama (1959). He showed that the pitch of a tone (80 phon) increased foveal absolute sensitivity to white light at the initial moment of tone delivery (from 1/7 second up to around 2 seconds). This was true for tones of 9,000, 3,000, 1,000 and 400 cps. In some cases lower tones of 300, 200 and 100 cps decreased sensitivity at the onset. Studies were made up to 4 seconds and at that point most of the effects had vanished. Similar results were obtained when loudness was varied. For a tone of 1,000 cps; 100, 80 and 50 phon gave increased foveal sensitivity while a 100 cps tone gave decreased sensitivity for the same loudness levels. Peripheral sensitivity exhibited the same general tendency as did different positions within the visual field. The method used was a combination of the method of limits and the method of constant stimuli.

Serrat and Karwoski (1936) found no effects whatsoever when they tested the effect of sound (410 cps) on the threshold for monochromatic light of 506 mμ and 710 mμ. Two methods were used, a method of limits where the sound was heard until the light

was shown and a method of constant stimuli where sound and light were presented until the subject made his judgement.

O'Hare (1956) did an experiment where the reversed effects were studied, namely the effect of visual stimulation on absolute auditory sensitivity. He used four pure tones of 200, 700, 2,000 and 6,000 cps. Thresholds were determined by the method of limits in 1 db steps while the subject fixated a light patch. The subject wore goggles with coloured filters (yellow, green, blue, red and black). Brightness varied for the different colours. The subject's attention was directed to the auditory stimulation. The results are not easily described. Yellow (brightest) increased sensitivity in all cases. Sensitivity to the 6,000 cps tone was decreased by all the colours except yellow. Sensitivity to the three lower tones was increased in almost all cases. Brightness is not the affective stimulus dimension since yellow, the brightest, showed a tendency to exert less and less effect from low to high frequency tones. In addition, the other colours did not differ in their effect even though considerable brightness differences did exist.

The present author started an experiment in an attempt to repeat O'Hare's, but was forced to stop because a continuous habituation over several sessions made all intermodal comparisons meaningless. These effects occurred even with trained subjects.

Gerall and Snyder (1962) showed that nonspecific muscular tension (weight lifting) did not affect the auditory threshold of a 1,000 cps tone. (Compare the parallelism suggested between head-tilt and auditive stimulation mentioned on page 55.)

In the Russian investigations reported by London it is shown that white light increases and no light decreases auditory sensitivity. Monochromatic green light increases and red light decreases auditive sensitivity.

Gregg and Brogden (1952) studied the effect of "set" on simultaneous visual and auditive stimulation. Absolute thresholds were measured on a 1,000 cps tone (method of limits) with no light and with two intensity levels of white light. The main result was that the group responding to both light and tone showed a decreased sensitivity while the group not informed about the light showed an increase in sensitivity. In both groups the difference was pro-

nounced with increasing light intensity. See also Halliday and Mingay (1961).

A similar experiment by Thomson, Voss and Brogden (1958) studied the effects of sub- and supra-liminal visual intensity (white light) on the absolute threshold of a 1,000 cps tone (method of limits). One group received instructions to respond both to the light and to the tone. The other group fixated only the light. Two separate effects were found. The group responding to both light and tone showed a decrease of sensitivity at subliminal levels of light and both groups showed a continuous increased sensitivity at supraliminal levels of light. In the last two experiments some doubts arise as to whether the control was sufficient.

Hartmann (1934) measured pitch and loudness discrimination using the Seashore records under simultaneous light stimulation. He found that strong general illumination enhances the acoustic stimulus when the light acts as a background, but acts inhibitory when the light is perceived as focal.

Gilbert refers to a number of experiments, all giving data indicating that the pitch of a tone is perceived as higher in the light than in the dark. It is suggested that this may be a secondary effect of increased intensitive sensitivity (i.e. increased apparent loudness) with visual stimulation.

Child and Wendt (1938) studied the temporal course of the effects of visual stimulation on auditory sensitivity. The auditory stimulus was a 1,000 cps tone, .16 second in duration, and the visual stimulus was white light (approx. 90—100 db), .1 second in duration. The maximum increase in sensitivity appeared when the light preceded the tone by .5 second, the effect with simultaneous presentation being somewhat smaller.

Working with differential sensitivity of a tone (500 cps, 60—70 db) as the original stimulus and white light as auxiliary stimulus, Treisman and Howarth (1959) found that the threshold fell continuously when the interstimulus range was changed from 1.5 to 0 seconds. It was minimal when the stimuli were simultaneous. Moreover, when the auxiliary stimulus was presented after the original stimulus, a decrease in the threshold occurred up to 0.5 to 1 second. They point out that the inputs appear to be stored until

the auxiliary stimulus is presented and a lowered criterion can be applied to them.

The interval of 0.5 to 1 second is similar to that for decay of peripheral sensory information found in experiments on the span of apprehension by Sperling (1960).

Intramodal auditive "prewarning" gives rise to similar effects as was shown by Rubin (1960). See also the idea of the "psychological" refractory period of Davis (1959).

Howarth and Treisman (1961) working with near threshold auxiliary stimulation have obtained results suggestive of how this process may function. Their theory claims that the effect is due to the auxiliary "warning" stimulus reducing the subject's uncertainty about when the threshold stimulus will occur. With simultaneous presentation a summative effect might occur, perhaps even a statistical summation which would indicate that the two threshold decisions are taken independently.

In Treisman (1962) it was shown that intensity of the auxiliary stimulus did not affect the extent of the lowering of the threshold. If the inter-stimulus intervals were randomized the threshold was decreased for long intervals, but not for short. This may be regarded as the reduction in subjective uncertainty lowering the subject's threshold during a temporal range of expectation during which the original stimulus is expected to be presented. Signal detection theory was shown to be able to predict the degree of threshold fall.

The Treisman and Howarth reports do attempt an explanation. However, they fail to resolve the problem of how in some instances the threshold is lowered while in others it is raised under identical temporal conditions, and of how both effects can occur with simultaneous presentations of the original and auxiliary stimulation. One suspects that different types of effect are involved. The auxiliary stimulation may have an arousal or depressant function in some cases while in others the expectancy function may be dominating. Instruction and set play a crucial role. Apart from these effects, "pure" sensory effects may exist as suggested by the experiments on colour sensitivity and auditive stimulation. These latter effects may be of the same type as the

depression and enhancement phenomena observed in brightness responses as the context is varied, see e.g. Diamond (1960). Another example is the increase of the threshold of fusion of paired light flashes occurring with electrical shock coinciding or preceding the flashes, Horn and Venables (1964). They suggest that the reticular system may play a role in mediating these effects and cite indirect support from Lindsley (1958), Steriade and Demetriscu (1962). Several alternative physiological explanations have been attempted. Their validity are, however, confined to rather specific situations.

Jaffe (1956) studied inter-modal figural after-effects and showed these to be interpretable in terms of the AL-theory of Helson. The same approach is taken by Bevan and Pritchard (1963 and 1964) in two experiments on loudness judgement. In the first experiment subliminal tones were shown to serve as anchors and to shift the scale, increasing the scalar distances between the series and the anchor.

In the second intermodal situation, brightness of light served as anchor and "paradoxical" effects were found. The shift for visual anchors, equated with the auditory anchors above the test series, resembled that produced by an auditory anchor below the series. The effects could be reversed by increasing the intensity of the light. The judgement units and language used was found not to affect these effects.

4.3.2 *Dynamogenic sensory interaction effects as studied with conditioning techniques*

4.3.2.1 *A short review*

Another line of approach to sensory interaction is to be found in experiments employing conditioning techniques. Using these techniques, the range of sensory interaction is broadened, as it has been shown that the effects of auxiliary stimulation may be acquired or altered by practice.

London reports that conditioned "sensory reflexes" have been studied in the Soviet Union since the 1930's. It was found possible to condition changes in e.g. electrical sensitivity of the

eye, CFF and peripheral sensitivity to e.g. tones and temporal intervals. Sokolov (1963) describes a more specific line of experimentation building mainly on Pavlov's concept of the orienting reflex [Allen, Hill and Wickens (1963)]. Relevant for the problem of sensory interaction is one essential feature of this concept. With any change in stimulus the development "takes exactly the same form irrespective of whether the stimulus used is stronger, weaker or of different quality". A review of Sokolov's work will be given later. I will start with a review of some experiments on sensory conditioning in order to illustrate the main technique.

Cason (1936) reports that when two stimuli—a light and a sound—are presented simultaneously, a facilitating effect is noticed. This effect is such that a stimulus affecting one of the two senses used, increases the intensity of the other sensory response. The increase is measured as an increase in the differential threshold between two stimuli affecting the same sense. After training, i.e. the two stimuli are presented together a number of times as in conventional conditioning, a stimulus affecting one of the two senses had the effect of decreasing the intensity of the other sensory response. The inhibiting effect was greatest when a motor reaction was performed during the training period. Thus, Cason finds an initial facilitatory sensory interaction effect and the direction of this effect can be reversed by training or conditioning.

Brogden (1947) paired a light stimulus with a sound and subsequently paired the sound stimulus with an electric shock. In a test series the light stimulus was shown to elicit the response (pressing of a telegraph key) conditioned by the electric shock. This finding is seen as an instance of sensory pre-conditioning.

In later experiments by Brogden (1950) and Brogden and Gregg (1951) the findings of the first experiment were confirmed. In Brogden (1950) a tone paired with a light was presented to one group of subjects while a control group was given only the tone. Subsequently, auditory thresholds were determined using stimulation of tone and light and tone alone. The subjects in the experimental group showed a lower auditory threshold for the conditioned "light and tone" as compared to the condition "tone

alone". The control group showed no difference in threshold between the two conditions. The inference made is that some relation between tone and light was established during the training session. The interpretation of this experiment should be compared to the reasoning pursued by Howarth and Treisman (1961) described earlier.

Aiba (1963) employed the same technique to see if the absolute light threshold could be conditioned. Using a 1,000 cps tone (70 db) as conditioned stimulus he found a subsequent increased difference between a control group—having a threshold level—and a conditioned group as regards the absolute light threshold. The conditioned group showed a small increase. The evidence is not conclusive as the small difference (around 1 db) may be accounted for—apart from conditioning—by e.g. changes in the criterion of light/no light following the pairing of supra-threshold light and sound. Another fact that casts doubt on the conditioning explanation is that the conditioned effects are not retained from day to day. Using a more intellectual stimulus material—nonsense syllables—Forrest (1957) showed that increased auditory familiarity resulted in a reduction of the visual recognition threshold.

4.3.2.2 *The Sokolov theory*

I have chosen to describe the work of Sokolov in somewhat greater detail, because of two reasons. One is that he appears to be the only worker who provides an elaborated alternative to the compact psychophysical tradition in this field. The other reason is that the conditioning theory as put forward by Sokolov provides a way of relating changes in absolute and differential thresholds to supra-threshold reaction changes. This latter problem is further dealt with in Section 4.

For Sokolov (1963) the process of perceiving a stimulus is a continuous reflex act of conditioned and unconditioned reflexes. This chain of reflexes brings about changes in the functional state of the receptor system and these changes determine the effectiveness of stimulus impact on the system. The central end of the

receptor system or analyser has the structure of an afferent-efferent organ which is able to control lower formations as well as receiving stimulation. Sokolov observes that this fact is important as e.g. the eye hitherto has been considered as a purely afferent organ. The reflex control within the analyser can be mediated through:

1. The descending efferent fibers running in the sensory nerves.
2. The autonomic nervous system; the following elements may be involved:
   a) The sympathetic (and parasympathetic) nerve supply to the receptors.
   b) The effects of the sympathetic nervous system on the functional state of the cortex.
   c) The neuro-humoral system.
   d) The indirect, secondary action of autonomic reactions on the internal organs, particularly the vascular system, and consequently on the excitability of nervous tissue.

Thus, during the process of perception, seen as a series of reflex acts, the effects of a stimulus are continuously changing. Each reflex is a functional system of its own, including control mechanisms. Orientation, defence and adaptation reflexes are the most important ones biologically. The orientation reflex is a primary response to any stimulation. It occurs to any "new" stimulus and involves a variety of activity in muscles, eyes, ears, head and limbs, ensuring optimal perception conditions. A major feature of the orientation reflex is its extinction under repetitive identical stimulation. The orienting reflex seen as an independent functional system comprises a range of reactions like motor components, endocrine and glandular components or autonomic reactions, all realizing the goal of the reflex to increase the analyser sensitivity. The connection between the orientation reflex and the mechanism for reflex control of analysers was not found until recently. Besides the orienting reactions brought about by any change of stimulus, specialized reflexes occur which deal with the quality and intensity of the stimulus in operation. One type is adaptation reflexes, adapting the analysers to the level of

stimulation. When the stimulation reaches a certain level of intensity a defence reflex starts to operate. The similarity between the two types of reflex is that they constrict the action of the stimulus. The adaptation reflexes operate on one analyser while the defence reflex concerns the whole organism. Both types of reflex initiate generalized reactions, but they differ in their final result, the first establishes contact with the stimulus, the second tries to break contact with the stimulus.

It has been shown that all three kinds of reaction can be conditioned to non-signal stimuli and that these "sensory conditioned reflexes" provide another mechanism of cortical control of analyser sensitivity, as cortical centres are assumed to participate (in some form) in all unconditioned reactions.

Perception cannot be understood unless each analyser is regarded as a combination of several afferent systems and combinations of interacting unconditioned and conditioned reactions are studied. Considering the temporal sequence of an unconditioned reflex, it is proposed that certain aspects of the unconditioned stimulus can serve as signals of its other qualities, which means that each phase in a continuous impulse formation can be, or become, a signal for the increase or decrease of subsequent impulses.

Two types of mediating processes, that embrace unconditioned and conditioned reflexes are found to control the sensitivity of analysers, i.e. intra-analyser and inter-analyser connections.

The "sensitivity" of an analyser is inversely proportional to the threshold, i.e. "the lowest intensity of a stimulus acting for a sufficiently long period capable of producing a sensation". Threshold measurement is one way of estimating sensitivity, although it cannot be used universally, e.g. when precise assessment is needed or when sensitivity to non-signal stimuli is asked for. It is preferable here to work with either a) local reactions in the receptor or nervous element involved, b) electrical activity in the cortical projection areas, the excitation subsequent to c) the orientation reflex, d) the specialized adaptation reflexes, e) the defence reflex or the variety of f) conditioned reflexes which can be formed. Each of these measures have their limita-

tions and advantages and must be applied and interpreted with know-how as some reflect the sensitivity of an analyser as a whole which some do not, and some of them reflect changes due to inhibition and extinction. Sokolov points out that "the problem of the essential intrinsic sensitivity of the analyser remains unsolved". He distinguishes the threshold of reaction and the threshold of excitability, the former taken as the lowest stimulus producing a just noticeable reaction, the latter being the lowest stimulus exciting the whole analyser including its central parts. An important method of estimating the true analyser threshold is to compare the two types of threshold for different reactions, thus avoiding oversimplified conclusions.

Sensitivity measures fail to indicate how an analyser responds to supraliminal stimuli. There are instances where a raised threshold is accompanied by increased reactions to strong supraliminal stimulation. This ability of the analyser to respond to supraliminal stimuli is called reactivity and is measured by the Stevens' type of scaling e.g. An important problem for perception theory is the relation between sensitivity and reactivity. Generally the sensitivity is an indicator of reactivity, e.g. the Fechner type of logarithmic relation, but this relation may be upset as in auditory recruitment e.g. The orientation reaction, always appearing with "new" stimuli may reveal this difference.

Another important aspect of the state of an analyser is its lability, i.e. the maximum number of stimuli which can be registered per time unit. Lability can be measured as the critical stimulus frequency for fusion or in terms of the basic oscillatory activity of the analyser.

On the basis of this reasoning Sokolov chooses an electropolygraphic technique as bring the most efficient approach. This "simultaneous registration of a great number of reactions allows of differentiation between the activities of separate functional systems, although each particular reaction may be involved in several systems".

In a series of experiments, Sokolov has demonstrated characteristic forms of the reactions mentioned in the perception of non-signal stimuli, and he shows how the reaction change is also

characteristic when the stimulation is repeated or as auxiliary or extraneous stimulation is added. The studies of the visual analyser demonstrate:

1. Generalized orientation reflexes resulting in EEG changes toward an accelerated basal rhythm, eye movements, dilatation of the pupil, suppression of respiration and increased sensitivity to light—developing simultaneously with the galvanic skin reaction.

Auxiliary stimulation, e.g. sound, may thus increase light sensitivity through the orientation reflex. For intense light stimulation the increased central sensitivity is neutralized by decreased peripheral sensitivity. Darkness stimulation increases peripheral and decreases central sensitivity, which in this case fulfills a similar neutralizing function.

2. Local orientation reactions, within the central segment of the visual analyser, consisting of increased excitability in response to light and diminished excitability in darkness.
3. The photic driving effect, consisting of reproduction of the rate of rhythmic photic stimulation by the visual cortex, depending on the latter's excitatory state, which, in turn, is determined by orientation reactions.
4. Adaptation reflexes, effecting changes at the periphery, which comprises pupillary contraction in response to light and pupillary dilatation in response to darkness; both being similar to the defensive reactions of the eye, which can be brought into operation by the action of a stream of air directed on to the cornea, or by intense illumination.
5. Peripheral retinal adaptation reactions in response to light or darkness.

Sound gives rise to a combination of orientation and adaptation reactions in the visual analyser. If sound stimulation is repeated, the orientation reflex is inhibited and the increase of sensitivity of the visual analyser is neutralized. The response of the visual analyser is thus the result of a summation of orientation and adaptation reactions. The start and termination of stimula-

tion of any type initiates the orientation reflex. With repetition of stimulation the generalized orientation reflex stops whereas local reactions continue. This idea of "a stimulus as a complex giving rise to a combination of orientation and specific reactions provides the explanation of the effects produced by intermittent light stimulation". Applying a stimulus starts the orientating reflex, this leading to blocking of the alpha-rhythm. Then a local orientation reaction increases the excitatory state of the analyser and one can see the flicker frequency superimposed in the excitability changes. With the cessation of stimulation the orientation reflex occurs again.

Sokolov then gives a description of how conditioned adaptation reflexes develop. In a series of experiments it is demonstrated how conditioned orientation reflexes can occur on "novel" stimulation, where the novelty is that the action of the stimulus is not anticipated by the conditioned adaptation reflexes. "Conditioned orientation reflexes can be produced by stimulation of one analyser or by a combination of stimuli acting on different analysers."

The alterations that take place within the interacting reflexes of orientation, adaptation and defence are then studied when the stimulus or stimuli become signals, i.e. evoke reactions anticipating som future aspect of external agents. A stimulus may become a "signal stimulus" through instruction or by a process of conditioning. It is demonstrated that a relation exists between the functional state of analysers and the ease with which conditioned reflexes can be formed and directed. In this context the relations between orientation reflexes and conditioned reflexes, and the subsequent changes in sensitivity during the temporal sequence of temporary connections, are discussed in the light of recent experimentation.

The principal findings of Sokolov concerning the structure of unconditioned and conditioned reflexes are then analysed in the light of recent neurophysiological theory. The double set-up of pathways to different layers of the cortex, one specific, the other non-specific, are related to the three primary types of reflexes and their conditioned variants. The principles of a) interaction

between specific and non-specific paths for transmission of excitation and b) the feedback properties of the analyser as an afferent-efferent system, are stressed and imply that return connections, at various levels providing autoregulation, play a major part in analyser activity.

The adaptational reflexes are shown to be connected with the specific system while the generalized and local orientation reflexes and the defensive reflex operates over the non-specific pathways mediated through the reticular system.

Sokolov finishes by giving a hypothetical model to explain the experimentally evidenced selective extinction of the orientation reflex. The selectivity implies that the reaction can be elicited by other "new" stimuli after its extinction to one stimulus. This aspect is extremely relevant to me as it directly touches on sensory interaction phenomena.

Sokolov introduces the construct of the "neuronal model of the stimulus" suggesting a cell system in which information concerning attributes or aspects of a stimulus is stored. This model is built up during stimulation. If any aspect (intensity, quality, temporal aspects or compound stimuli) of the stimulus is changed at a new presentation, the stimulus no longer coincides with the "neuronal model" and an orienting reflex occurs. (The stimulus may here be regarded as a Gibsonian type—i.e. a complex one as in Gibson (1959)). Sokolov compares the neuronal model concept with the extrapolating properties of the nervous system. Thus, the orienting reaction disappears for previously presented stimuli and in this way the model functions as a selective filter. Extinction of the orienting reflex is impossible in decorticate dogs, this fact having implications for the part played by the cortex. Other evidence suggests that repeated presentation of a conditioned stimulus also leads to the formation of a neuronal model. A conditioned reaction occurs only when the stimulus coincides with the model, and without inclusion of the reticular activating system. If a new stimulus is negatively reinforced, two independent models are formed, one for the positive and one for the negative stimulus and both reactions occur without any orienting reflex. When any stimulus is changed, the model does

not fit and "the blocking effect of the cortex on the reticular system is reduced and the conditioned reaction arrested". The reticular system in turn produces activation spreading through the cortex and tunes the analyser to increased sensitivity.

4.3.3 *Comment*

The sample of investigations reviewed above constitute a complex mosaic of results sometimes contradictory. In general the effects are small and the experimental results appear difficult to replicate. The critical question whether the effects found may be resolved as being the result of response biases of the subjects is seldom discussed. The functional relations among the independent factors are as a rule not well known and the experiments carried through must be regarded as exploratory. More integrated experimental evidence is needed before a more extensive hypothetizing could be made. The most elaborated theory so far—the conditioning theory of Sokolov—is built on qualitative experimentation rather than quantitative, and on the explanatory side extensive use is made of hypothetical constructs.

The most relevant antecedent, independent factors requiring more thorough study are:

1. The commonly observed differential individual susceptibility.
2. The dependability of the intersensory effects on practice and learning.
3. The temporal relations between auxiliary and basic stimulation.
4. The role of intensity, amplitude or magnitude variation in auxiliary and basic stimulation.
5. Relations due to "secondary" qualities of both auxiliary and basic stimulation (e.g. stabile-labile, peripheral-focal, figure-background).
6. The role played by instruction, mode of reporting and set.

1. The found differential susceptibility among individuals to the impact of auxiliary stimulation—and here agreement in the findings is at large—imply that group data ought not to be used before an analysis of individual data indicate that this is adequate.

It must be said, however, that the observed differential susceptibility may be caused by a variety of factors from hereditary and personality to instructional. It seems also safe to state that the observed variation in proneness in no instance has been adequately explained in terms of casual factors.

2. The effects of repeated stimulation, practice and learning cast the same doubt on the adequacy in using group data without preanalysis. Apart from the strict conditioning experiments there seem to be few investigations where these effects have been discussed more thoroughly. In those experiments where repetition of the auxiliary stimulation is studied, repetition appears to reduce the effects to zero. However, in some instances a cumulative effect even over days is observed.

3. Overlapping with the repetition issue is the problem of temporal relations between auxiliary and basic stimulation. If we use temporal in a broad sense, it may be helpful to split up this factor in i) durational relations, ii) interval relations and iii) relations due to order of presentation.

i) As for duration a general finding is that the auxiliary effects usually show a two-phase development, most often first increasing the sensitivity and later with prolonged duration returning to the original value or a decreased sensitivity. In some experiments the reversed relation is found.

The durational effects are of two types. The most common change occurs during a short period (0 to about 4 seconds) from the onset of the auxiliary stimulus, but sometimes this change takes place within the first hour—in one study mentioned by London (ibid.) reaching a maximum after 15 minutes, and then returning to zero after one hour. The other type of shift in the effects sometimes occur when the auxiliary stimulation is terminated. A decreased sensitivity may be followed by a phase with increased sensitivity and vice versa.

ii) The interstimulus interval (auxiliary/basic) most often maximizes the effects when the auxiliary stimulus coincides with or precedes the basic stimulus. Different optimum intervals have been reported in different experiments.

iii) This also in part answers the question of order of presenta-

tion, but here might be added the finding of Treisman and Howarth (ibid.) where a reversed order of auxiliary and basic stimulation was shown to increase sensitivity as well. Some storing mechanism was postulated as an explanation.

4. In a number of studies it is shown that different amplitudes or magnitudes of the auxiliary stimulus may yield different (even reciprocal) effects. These differential effects may also manifest themselves when duration of stimulation is varied simultaneuosly.

5 and 6. The impact of these factors are probably important. Systematic studies are, as far as I know, few. Many of the experiments reviewed use what ad hoc might be interpreted as set-inducing instructions and/or suggestive experimental set-ups.

4.3.4 *Visual acuity and auditory sensitivity*

Static visual acuity or spatial resolution is another type of visual sensitivity also said to be affected by auxiliary stimulation.

Findings from this type of studies ought to be at least suggestive in trying to relate intensitive sensitivity to visual acuity.

Gilbert (1941) summarizes Urbantschitsch's observations on patients with maladies in the ear. Visual acuity (as measured by Jaeger charts) improved with the course of treatment as hearing improved. The same type of findings are reported by later Russian experimentors (see Knox (1945 b)).

Experimental studies of heteromodal effects on visual acuity were initiated by findings of interrelations between the two eyes. Thus, the acuity of one eye is changed by diffuse illumination of the other eye. Acuity is said to be increased for black on white and decreased for white on black while sometimes acuity is increased in both conditions.

These findings have also been made using auditory auxiliary stimulation. Gilbert, Ryan, London, Bartley and Dember all have summaries of a series of apparently contradictory experiments by Kravkov (1934), Hartman (1933) and Serrat and Karwoski (1936). Curiously enough the experiments do not seem to have been repeated. Kravkov's original finding was that a 2,100 cps tone increased black on white acuity (stripes on a background) and

decreased acuity for white on black. Hartman found increased acuity in both cases and Serrat and Karwoski found no change whatsoever. Kravkov performed experiments suggesting an explanation in terms of irradiational effects–(for summaries see London and Ryan). After reading the articles and the reviews mentioned above one is inclined to consider the contradictionary effects inconclusively resolved. The reason for this is that the temporal sequences employed in the different experiments either vary or are not explicitly given. The same holds true for the loudness levels used. The maximum changes obtained never exceed 10 % and the effects are thus to be considered small. Individual susceptibility to the effects is not discussed to any extent. Inaba (1958) studied the differential effect on visual acuity (Landolt C) of tone stimulation as well as the effect of auditory stimulation on perceptual learning and found no sensory interaction effects.

I conclude that the question whether visual acuity may be affected by auditory stimulation is not answered in the affirmative. The effects are, if they are found, small and the direction may vary with the temporal conditions.

4.3.5 *Catalogue of explanations proposed for dynamogenic effects*

The experiments falling under (A) Table 1, exhibit a confusing picture. Although the presentation is brief some general conclusions are possible: the effects are most often small, labile and often hard to repeat even if replication experiments appear very similar. This seems to indicate that several factors apart from simultaneously auxiliary stimulation may affect the results. The intensity level of the auxiliary stimulation may determine the direction of the effects alone or in combination with temporal factors. The experimentation within the area is considered as exploratory. The theoretical interpretations given are in most cases eclectic situational descriptions making them inadequate for a more extended theory.

The explanations proposed range from phenomenological descriptions over psychophysical and conditioning theories to more

or less explicit neurophysiological model making and genetic speculations. In the theorizing during the last thirty years the picture is sometimes confused by the fact that political ideology at some stages has entered the discussions. This specifically holds for the genetic approach during the nazi-era in Germany[1] and to some extent parts of the Russian discussion under influence of materialisms pragmatic focussing of theoretical work expressed e.g. in the dogmatic Pavlovian propositions of cortical action (see e.g. Pick (1964)). No comprehensive texts on theorizing in the field of sensory interaction are yet to be found.

Any clearcut classification of the theories proposed is impossible as most theories employ models extending over several of the classes mentioned above and as most of them are tailor-made to explain specific issues. I will here confine the summary to a mentioning of some of the key concepts, key reasoning or key hypothesis to be found.

In the phenomenological descriptions a Gestalt-theoretical attitude is common. The descriptions employ concepts like figure and ground and perceptual set to describe the effect encountered. Sometimes a distinction is made between two modes of perception e.g. *perceiving* something "out there" and *sensing* something "inside". Essential is that extraneous stimulation may be either perceived or sensed. These theories are of a R-R kind establishing connections between introspection reports and observable reactions. In some instances genetic speculations are found building on evidence for the genetic and ontogenetic development of perception from undifferentiated responses to highly differentiated responses. Specifically the ontogenetic evidence is taken as indicating an interdependence of the senses.

The stricter explanations employing psychophysical theories favour signal detectability models, usually refraining from deeper physiological speculations. Another approach is based on the Helson theory of adaptation-level. Both approaches are strict S-R theories. Conditioning explanations are of two kinds. One Russian approach employs Pavlovian concepts, especially the

[1] The reader may find a good example in Jaensch (1938).

orienting reflex and the adaptation reflex. In this kind of experimentation highly specific physiological measures are used and the theoretical explanation is given in terms of neurological models of central activity. Another approach (found both in Russia and elsewhere) employs the conditioning paradigm but interprets the results in more gross behavioristic S-R terms. Both types of explanations stress that the range of sensory interaction may be broadened through acquired auxiliary stimulation effects.

The neurophysiological models use physiological concepts in two different ways. In some cases the models are to a certain extent built on physiological empirical facts, in other cases the physiological terms are used as hypothetical constructs. This double application of physiology is troublesome as some of, or parts of, some models turn out to be or may be suspected to be nothing more than low-order S-R paradigms. Without indulging in a deeper discussion on this issue I will here only give a catalogue of some of the most important explanatory physiological principles.

The Pavlovian theory of reflexes and cortical action has already been mentioned. It has connections to the theoretical views put forward by Lorante on the reciproxity of nervous action and Magoun on the functioning of the reticular system. Hebb's construct of cell assemblies may be mentioned as an example of the same type of explanatory principle.

It is further thought that unmyelinated fibers in close proximity may influence each other. Auditory and visual fibers under these conditions are found at several stages.

Changes in neural excitation, instead of changes in neural excitability (change in threshold) has served as an alternative explanation. This question has been approached by studying—along with changes in threshold—amount of positive irradiation caused by auxiliary stimulation (e.g. in the case of visual acuity changes with auxiliary stimulation). In Russian theorizing this reasoning appears under the rule of levelling and accentuation. This rule also emphasizes the role played by initial contrast between the object perceived and its background. The rule implies that when initial contrast is large accentuation of contrast occurs,

when it is small, levelling of contrast results. The physiological reasoning behind this rule is that additional stimulation (through e.g. auxiliary stimulation) is taken up to a higher degree by those parts in the original receptor organ that are strongly excited.

In line with Pavlovian ideas of cortical action an intracentral mediation of auxiliary stimulation is assumed. This assumption allows for one cortical center to cause excitation or depression of another cortical center (of another modality). This reasoning is very analogous to that pursued by Hebb.

The effects of electrotonic influence are commonly described in terms of ionic concentration and balance increasing or reducing the concentration of acetylcholine in the synapses. In turn this reasoning is extended to explain some of the reciprocal effects auxiliary stimulation has by postulating the mediating role of the autonomic nervous system. Research (London 1954) has demonstrated sympathomimetic and parasympathomimetic substances bringing forth these reciprocal effects through autonomic mediation. Analogous by different kinds of stimulation can be shown to be either sympathotropic or parasympathotropic.

The difficulty in getting the effects—utilizing different "labilizing" techniques—indicates that the modality-concept used with some looseness is convenient and that "the unity of the senses" is an idea not to be taken too literally.

4.4 *Intersensory Dependence and Consonance.* (B)

4.4.1 *Introductory discussion*

Intersensory dependence refers to changes in responses when an auxiliary stimulation is present simultaneously with the original one as in the last section, but here the changes are studied on supra-threshold levels. The problem of relating changes in absolute and differential thresholds (as defined through classical psychophysical methods) to supra-threshold reactions changes (as defined through some scaling process) is difficult. No general model allowing a complete description is available although several special cases have been described, Luce, Bush and Galanter (1963), Sokolov

(1963). A contributing factor is a lack of empirical data on these phenomena. Exceptions are the "attentional" variations studied by signal detectability theory, choice theory or neural quantum theory (Luce (1963)), the frame of reference shifts handled by the AL-theory of Helson (1959), (1964) and the reactivity-sensitivity distinction used by Sokolov (1963). Here only a brief catalogue of some of the problems involved will be given.

Conceptually "threshold" stands for the minute sensitivity or resolving power an organism possesses at a given instant. This minute sensitivity is impossible to measure directly and thus "threshold" is operationally defined by some statistical and experimental procedure, see e.g. Guilford (1954). The threshold is, while it stands for a limit on the R-continuum, always given as a certain value in the S scale. Any threshold value thus represents, by definition, a central value of a subjective transition zone. The minute sensitivity or the threshold inferred is assumed to change according to some distribution over the period of measurement. The meaningfulness of this instant threshold concept has been doubted now and then, e.g. Swets (1961), Sokolov (1963). Some of the specific difficulties in relating liminal and supra-liminal changes are outlined below.

I. Different processes may be at work in a) absolute threshold situations, b) differential threshold situations and c) supra-liminal judgement situations.

II. The discrimination tasks encountered in a), b) and c) differ. In a) a no signal—signal discrimination is done while in b) and c) a signal—signal or signal—standard discrimination are asked for. a), b) and c) could occur with or without background noise.

III. The judgemental criteria (cut-point arrived at by using a decision rule indicated by e.g. the stimulus error) determining the response probabilities may be chosen differentially in a), b) and c). For the multimodal case this point is theoretically untouched, Luce (1963).

IV. If in a) and b) a change in the threshold occurs (e.g. due to auxiliary stimulation) this may be seen as 1) an "arousal"

increasing 2) the instant sensitivity or 3) changing the criteria mentioned in III or 4) a combination of 2) and 3) or 5) as a reduction in the temporal expectancy when the signal or signal-signal will occur. 1) to 4) should vary with the intensity of the auxiliary stimulation while 5) should be independent of intensity variations.

V. If a) functions as an anchor-point for the R-scale, b) and c) are also affected. Equally reasonable is to regard a), b) and c) or some combination of them as conditional and thus jointly determining the anchor or anchors for the R-scale. Almost all response models proposed hitherto assume response independence.

VI. The problems mentioned under I—V are in turn dependent on the exact experimental conditions (number of trials, spacing of stimuli, presentation order etc.,) prevailing.

It seems safe to observe that no coherent theory—except for the qualitative conditioning theory of Sokolov—hitherto has been proposed and that recognition and detection theories are developing rapidly and may soon propose models adequate for these problems.

The difference between dynamogenic effects treated in the previous section and the supralevel effects treated here may thus not always be seen as different phenomena but rather as different aspects of the same phenomena measured with different methods.

Sometimes the auxiliary stimulation possesses the same attribute as the original one (e.g. brightness) and in these cases the *dependence* is also *consonant* with the original stimulation.

4.4.2 *Similarity of qualifications across modalities and related problems*

Intersensory dependence in *consonance* between original and auxiliary stimulation may be approached in different ways. The classical approach was through cross-modal matching, see von Hornbostel (1938), Ryan (1941). The typical method of investigation was to determine the universality of cross-modal matchings of e.g. brightness, dullness etc. over a group of subjects. The

attributes matched were thus considered common to several modalities and this was thought to be evidenced by a universal consequency in the matchings of large groups of subjects.

Another method used for the same problem is to start e.g. with a light of a certain brightness, match this light to a tone, the tone to an odor and then match this odor back to a light hoping that the initial brightness of the light is arrived at.

The results are hard to evaluate and far from conclusive. Further the relation of this type of experiments to the problem of sensory interaction is unclear. It is hard to get an univocal picture of what the subjects are instructed to do in experiments of the type mentioned above. The common instructional feature stresses judgement of similarity. Similarity matchings may, however, build on a) comparisons of common dimensions (attributes), b) comparisons of vector patterns in common dimensions (e.g. comparing transposed melodies or speech-sounds), c) comparisons of vector patterns from dimensions not in common, d) degree of association to a common third (stimulus) dimension, e) allocating of a), b) or c) to a preference dimension.

Alternative b) and c) above seem to be those usually denoted or explained by some procedure of "conventional analogy."

The logical difficulty is that consistent or consequent matchings naturally can be made by conventional analogy and reversed that analogy may not be employed where attributes are comparable between modalities. Ryan refers to one experiment where fishes trained to select one in a pair of visual brightnesses were shown to choose consistently one of a pair of odors. Control showed that fishes do not have this tendency without training. Few experiments has been performed with animals or young children unable of conceptual analogism.

The technique of cross-modal matching is also from quite different points of departure frequently used in recent psychophysical scaling experiments. Here one is uninterested in whether the cross-modal comparisons occur through a natural equivalence of attributes or through verbal or conceptual analogy. Implicitly assumed is, however, that the subjective scales from the different

modalities are unaffected by the procedure of presenting heteromodal stimulation. Some of the experiments to be mentioned further on cast some doubts on the legitimacy of such an assumption. The AL-theory of Helson (1964) implies the same doubts from another approach.

A third type of experiments bearing some resemblance to the problem of consonancy are those studying certain types of cross-modal transfer (see e.g. Gaydos (1955 and 1956)). In these experiments it seems necessary to assume either that a common attribute or aspect is to be found initially between the stimulation patterns given over different modalities or that the subject learns to form associations between different attributes in the two stimulus patterns. This last approach still implies that some common aspect can be found or invented from the start as a basis for the associations to be formed. The association paradigm pushes the origin of the common aspects on earlier experience and thus avoids giving a resolution of the problem.

The connections between the three types of examples mentioned and sensory interaction are unclear and in some cases dubious but all three implicitly allow for a unified working of the different senses at least on a central judgemental cognitive level. This may imply that sensory interaction can be studied either as a "pure" sensory (or physiological) phenomenon or as an intellectual (perceptual, cognitive) phenomenon i.e. reinstating the difference between sensation and perception.

4.4.3 *Changes in quality due to heteromodal stimulation*

The experiments reviewed by Ryan usually employ simultaneous heteromodal stimulation and the subject is asked to give verbal reports of qualitative changes in the perceptions emanating from one modality as it is accompanied by auxiliary stimulation.

Colour quality could be affected by tones when they were of high intensity and difficult to localize at the same time as the colour was made labile by short exposures, low saturation, using film colour etc. These conditions of perceiving are to a high degree

dependent on the instructions given to the subjects. Common to the experiments mentioned under (A) Table 1 is this "suggestive" type of instruction.

The changes reported were different for low and high tones. The direction of low-tone effects is described by adjectives such as darker, warmer, more unclear etc. while high-tone effects are described by colder, brighter etc. Surface colours do not seem able to affect at all. Similar findings are reported by Mulholland (1956) working with illusions of rotating stimulus objects. The same type of effects has also been found for visual stimulation upon 1) auditive perception, 2) temperature perception and 3) tactile perception as well as for auditory stimulation upon tactile perception.

Studies on visual flicker and fusion is a bit difficult to refer to any specific category in the scheme used here. Most studies concentrate on studying changes in the CFF (the critical fusion frequency) but often this interest is coupled with the problem of qualitative changes in fusion or flicker above or below the CFF. In addition the phenomena are sometimes regarded as a parallel to apparent motion. Flicker and fusion ought thus to be considered under (A), (B) and (C) according to the notations in Table 1. For the sake of convenience I have chosen to place the main discussion to (B) indicating the resemblance with problems under (A) and (C).

Several experiments indicate that CFF may be affected by several types of auxiliary stimulation. The effects are not easily explained and several contradictionary results are to be found. The same is true for qualitative changes of fusion and flicker. Dissonant auditive stimulation increases the degree of flicker and raises the CFF while harmonic stimulation has the reversed effects. (Tactile stimulation yields similar effects.)

McCrosky (1957) obtained a lower CFF measured simultaneously with white noise as compared with a silent condition. Levine (1958) studied the effect of intensity of a pure tone (1,550 cps) on the CFF. CFF was shown to depend on the brightness of the target and the intensity of the tone. At low brightness levels no sensory

interaction was found. Miller (1953) found no effect on CFF by an 8,000 cps tone of 90 db loudness.

Intermittent auditive auxiliary stimulation synchronized with the visual flicker increases the CFF as compared to unsynchronized (out-of-phase) auditive stimulation according to Ogilvie (1956). He explains the results in neurophysiological terms suggesting that the temporal resolving power of the visual nervous system is increased by a hetero-modal summation, and decreased in the unsynchronous condition.

Spiegel (1964) showed the influence of size-constancy off-setting the normally expected decrement in CFF following a reduction of the retinal size of the stimulus.

If continuous and intermittent auditive auxiliary stimulation effects are compared, intermittent stimulation exerts the greatest influence (von Schiller [1932]). Knox (1945 a) has dealt with the problem of whether visual flicker can be induced by the presence of auditory flicker under conditions otherwise giving fusion. Relating the results of von Schiller to his own, Knox concludes that "visual flicker cannot be induced by auditory flicker but when visual flicker is present its degree of pronouncedness can be increased". This might be seen as an instance where the threshold is left unaffected while the subjective supra-threshold values are affected.

Knox's interpretation is in contradiction to von Schiller and other older experiments as well as to the Russian findings considered below. Knox's conclusions are not too convincing. 1) His data show a systematic (but small) decrease in the CFF from intermittent auditive stimulation over continuous auditive stimulation to silence. 2) The subjects made a large number of judgements ($n = 40$) on each of four conditions. Practice or adaptation effects may thus have covered initial bigger effects.

In another study Knox (1945 b) measured the effects of auditive stimulation on the pronouncedness of visual flicker by asking the subjects to equate the two types of visual flicker. Extensible effects were found both for fine and coarse visual flicker. The set induced by instruction had a comparatively small but systematic influence.

Time order errors are considered and are said not to resolve the differences found.

London (ibid.) reports that illumination of one eye raises the CFF but hinders the reduction of CFF observed in the other eye during dark adaptation.

The auditory stimulation (800 cps, 85 db) exerts different effects depending on the wave-length of the light used. CFF is reduced for green light and raised for red light. For white light, central CFF is raised while peripheral CFF is lowered.

Also reported is that CFF for a low intensity light is reduced by auxiliary stimulation, CFF for a high intensity light might be raised under the same conditions.

Allen and Schwartz (1940) report raised CFF for both short and long wave-length light under auxiliary auditive stimulation.

Another experiment by Behar and Bevan (1961 b) is suggestive in this dilemma. They studied subjective durations of noise filled and light filled intervals with anchors below or above the series. The problem was to study intermodal relations in judgement by comparing shift of the subjective scales for durations with intra- and inter-modal anchors. Intermodal anchor effects could be induced but were of a smaller magnitude as compared to intra-modal effects. It was shown that intermodal anchors close to the series were equivalent to intra-modal anchors while intermodal anchors removed from the series lost in anchor effect. This loss was greater for auditory than for visual intermodal anchors.

These results are suggestive in indicating a cognitive or intellectual aspect of the phenomena. Instruction and set may play a crucial role in determining the extent and direction of the effects. The impact of the intermodal stimulation may either be seen as a figure or split up into a focal figure part and a peripheral background. In this situation the auxiliary stimulation may thus either be assimilated or contrasted to the original stimulation. The result of either way of perceiving may be an enhancement or a depression of the attribute judged. In order to predict the outfall an initial equalization procedure must be done. This point will be taken up more extensively later on.

Other types of phenomena affected by auxiliary stimulation are also to be found, London (ibid.). Simultaneous contrast is heightened by auditive stimulation (800 cps, 75 db) if the initial contrast is high. The reverse holds true if the initial contrast is low. Visual after-images are also able to affect. The course of the extinction may be changed or (for loud tones) completely depressed. See also Ahwaki (1961).

4.5 *Intermodal Relations in Perceiving Spatial Qualifications* (C)

One difference between the type of effects found under this heading and those under 4.3 and 4.4 ((A) and (B) according to Table 1) is that the experimental situations employed here are said to be more realistic, involving meaningful parameters. All orienting or localizing reactions are made in the visible world of Gibson (although he calls it visual). The impact of stimulation upon perception is always conditional on the bodily or rather postural frame of reference in which external and internal "objects" are related.

The statement about meaningfulness is not the author's own reflection but is found in most texts dealing with the topic. It is not apparent what meaningful really stands for, as the neutralness encountered in the last two sections is defined in terms of how the experimentor perceived the experimental situation as compared to his everyday life situation. From this obviously not follows that localizing a sound is more meaningful than judging if it is heard or not. The meaningfulness might lie in the fact that localizing a sound is a more complex act to account for than a threshold judgement or that the localizing act is thought of as occurring more frequently in everyday life. The fact that something is perceived in relation to other things in three dimensional space and/or in time does not automatically make this something more meaningful, as the meaningfulness still must be defined in terms of the subjects aims or purposes.

Let us here confine the difference between (A) and (B) relative

to (C), Table 1, to the fact that perceiving spatial qualifications are conditional to a postural frame of reference, while liminal and supraliminal judgements of quality and intensity are not.

4.5.1 *Changes in localization due to heteromodal stimulation*

As a background I refer to the discussion and review presented in Chapter 3, sections 2 and 3. From those sections it is clear that spatial localization in all natural settings involve several sense modalities. If the main information channel is blocked or distorted, a subject may, within certain narrow limits, compensate for the deficit in information by relying on, or substituting information from other channels.

Distortion of stimulation patterns in one or more senses is, however, always resulting in a change of the perceived spatial localization.

Ryan (ibid.) reviews a series of experiments showing that subjects presented to a heteromodal situation and asked to localize the stimulation spatially in one modality tend to close the heteromodal stimuli together. The same observation is made when afterimages are studied. This "inductive" power is strongest for visual stimuli and weaker for auditive and tactile stimuli. Repetition or practice strengthens this inductive power, probably cumulating it through temporal summation.

In brain-injured subjects, sounds on the injured side tend to be subjectively localized too far to that side. (Difficulties of pointing are ruled out as an explanatory principle.)

Rolling the eyes (with closed lids) caused a sound to be localized in the opposite direction while fixating brought the sound in the direction fixated. The effects were more pronounced in brain-injured than in normal individuals. The reversal of effects between the rolling eyes and fixating conditions are interpreted as changes in "set". Further, moving the eyes to one side is a different task from looking to one side. Anecdotical results gotten at the desk while writing this show that the same results are received when I try to mark the sagittal plane with a pencil under the two conditions. Proposed explanations of this phenomena suggest that a

basic physiological tendency is to turn toward the object perceived. This tendency is increased in brain-injured individuals by lesions affecting the postural system.

4.5.2 *Cooperation of modalities in production of spatial qualifications. Movement and auditive stimulation.*

Most of the studies reported by Ryan and Gilbert and later investigations have dealt with different forms of apparent movement, most often stroboscopic motion, Rock and Ebenholz (1962). The problems studied and effects encountered are similar to those previously mentioned under (B) namely flicker and fusion experiment.

If dissimilar objects are presented intermittently, movement is regularly not seen. If auditive stimulation occurs simultaneously, regular auditory rhythms are shown to facilitate movement while irregular rhythms inhibit or distort the movement. Hard to control are the effects of suggestion.

Ambiguous stroboscopic movement—i.e. several lights arranged so that several patterns of movement could be perceived—turns out to be less ambiguous (a reduction in the number of patterns able to perceive) when auditory rhythms are heard. The speed of the motion is also said to be affected. Taylor (1958) studied the effect of auditive stimulation on autokinetic motion and found complex relations impossible to interpret within the frame work of the sensory-tonic theory.

Gilbert (1939) made an experiment on how the effects vary with the degree of synchronizing between the visual and auditory rhythms. A 1,000 cps tone was used as auditive stimulus and a stroboscopic set-up displayed two alternating white light spots. The measure used was the range of frequencies within which movement was perceived.

Unsynchronized presentation of tone and light depressed the range within which movement was seen in average with 18 % as compared to a silent condition. Synchronized sound and light tended to facilitate movement, although a bimodal distribution of results made an univocal interpretation impossible. The intensity

may have a separate effect. In a second experiment, mild and strong electric shock was given simultaneously with the right and left flashes of light. The measure was the frequency threshold between alternation and movement. Mild simultaneous shock decreased the threshold or completely inhibited the perception of movement. Differences in individual susceptibility and a general adaptive reaction were noted.

The general effects observed by Gilbert should be compared to those found by Frankenhauser (1959) concerning the perception of time intervals during varying simultaneous auditive stimulation. Frankenhauser's experiments will be discussed in some more detail in section 4.6.

Experiments studying real movement in connection with sensory interaction are few. Those interested in some aspect of the relativity of motion perception have most often done experiments on visual motion, in a few cases varying the visual context. For representative recent bibliographies see Mandriota, Mintz and Notterman (1962), Cohen (1964) and Mashhour (1964).

Johansson (1950) reported an experiment where auxiliary stimulation is applied. His main problem is to systematize the factors responsible for the changes in perceived velocity of a moving object when a second object is present in the field. (This may tentatively be seen as an instance of intra-modal sensory interaction.) When time was adopted as the velocity variable and frequency of movement was varied, different results were obtained as compared to when length of movement path was varied, even if the physical velocity was the same. When the temporal and the spatial components were in conflict it was shown that the former mainly determines the perceived velocity.

If the frequency is separated from the motion itself (e.g. by a shutter arrangement) the dominance of the time factor is diminished but it is still a determining factor of the perceived velocity. The velocity experienced is here the resultant of two in part contradictory components—equality of motion and equality of duration. Johansson asks the question whether "a completely independent experience of time" may influence the perceived velocity of motion. The previous results hint in that direction.

The experimental set-up consisted of two fields, each containing a light spot moving back and forth. When field I is presented, a sound signal (800 cps, 0.2 sec. duraion) was heard at 0.8 second's interval. When field II was shown the signal was heard at an interval of 1.2 seconds. Using the method of reproduction the subject adjusted one of the velocities until the two motions were perceived as having equal velocity.

The results show that the velocity in field II had to be increased over the objective velocity equality in order to be perceived phenomenologically as equal.

Johansson summarizes his findings by citing C. F. Brown (1931) by saying that "the time stream flowed more slowly in field II."

Further is observed a marked differential individual susceptibility to the influence of the auditive auxiliary stimulation. Thus, in two out of seven subjects no effect whatsoever was observed. This is an important difference between this experiment and the other reported by Jonansson in the same article.

In his discussion; Johansson states that "the experiment emphasizes, in an intriguing way, the role the experience of time plays in determining the velocity; and that it again confirms the fact that an experience of velocity can be a compromise between, or the resultant of, different components within the total sphere of the experience" (op. cit. pp. 77).

The experiment reviewed above is the one that initiated the present work. As such it has been reviewed in some detail. I will make some comments concerning the ideas and questions it aroused and continue this discussion in Chapter 5, where my own experiments are reported. The complete *independence* of the auxiliary auditive stimulation may be questioned. The time experience induced is only "completely independent" in the sense that it is a) auditively presented and b) the frequency of the sound does not coincide with the frequency of the motion. It is, however, *dependent* in the sense that it is presented simultaneously with the visual motion and it disappears when the motion disappears. This mode of presentation naturally suggests that the sound and the motion should be perceived as belonging together. Further, the

sound and the motion emanates from about the same spatial site.[1]

In the experiment the method of reproduction was used. Comparisons between the two velocities were made at only one point on the velocity continuum. Does the effect go in the same direction for other velocities as well? Is it possible to use subjective scaling methods to study this effect over an extended range of velocities?

In the discussion it is said that the perceived velocity is influenced by the experience of time. It is possible to determine if time is perceived as time, frequency or "acoustic velocity" viz. "the compromise between, or the resultant of, different components within the total sphere of the experience" may be based on the same or different attributes of the complex stimulation pattern received. The intermittent sound may be perceived as velocity/frequency as well as the visual motion may be perceived as velocity/frequency. Naturally, it is meaningless to ask *what* attribute a subject judges but it may be meaningful to ask if a subject uses the same attribute perceiving the sound and/or the motion. Subjective scaling data from this type of experiment may be analysed to spread some light over that question.

Another question that may be asked is whether the effects observed are to be considered as response-bias or as changes in the subjects' perception (in the sense that they can be measured by different methods more or less susceptible to response-bias effects).

4.5.2 *Reorganization of spatial properties under influence of reversal or distorted cues*

As this problem is discussed in Chapter 3, sections 2 and 3 in relation to the role of learning and sensory-motor activity, I will here only repeat the conclusions arrived at. The interpretations from this type of experimental work are not straight forward and

[1] This touches the question of casual integration, i.e. that sounds are located to objects thus making it difficult to separate the place of the sound and the place of the moving light. The light may be seen as being the source of the sound. As far as the author knows experimentation on factors underlying heteromodal casual integration are confined to Fisher (1960 and 1962).

simple. The idea that inversion/reversal or distorted cues conditions simulate the perceptual development may be argued. Neither learning or sensory-motor activity alone could fully explain the results obtained. The earlier interpretations of the reorganization (readaptation) experiments have been made quite unconvincing in the light of the results that have been arrived at by e.g. Smith and Smith (op. cit.). The degree of distortion to which animals and human subject could readjust themselves are much smaller than hitherto has been believed.

The experiments mentioned in Chapter 3 indicate and stress the mutually dependent importance of sensory interaction and past experience. They also point out that the basic organization of the perceptual system is not well understood.

4.6 *Intermodal Relations in Perceiving other Nonspecific Properties of Objects*

4.6.1 *Background*

This section deals with non-specific properties of objects. The word objects must be understood to refer to systems possessing perceivable attributes or properties rather than to real objects. Further the review will be restricted to experiments dealing with the perception of time or rather systems or objects having temporal properties. It might seem a bit farflung to discuss time as a non-specific property of an object, but as I here (and in the last section above) has regarded time or rather temporal relations as an aspect of e.g. a moving object it appears reasonable. As far as this review goes, judgement of time is always considered to be a reaction on some kind of stimulation, and in my own experiments reported further on, time always enters the discussion related to judgement of velocity of motion.

4.6.2 *Empirical findings*

Frankenhauser (1959) p. 69 ff. reports a series of experiments dealing with the influence on the perception of time by variations in external conditions. She varies a) the amount of change in the

background, b) the intensity of a constant background and c) the intensity of the stimulus interval judged.

She found that intervals of 10–70 seconds appeared subjectively longer when a metronome was beating at a fast rate than when beating at a slow rate. This holds true for present time and past time measures.

Auditory signals with random duration of signals and empty intervals showed the same effect. In these experiments the amount of change in the background was varied.

When the intensity of an auditory background was varied—high intensity tone, low intensity tone and no auditory stimulation—it was shown that this had no effect on the relation between objective and subjective time.

In a fourth experiment, the effect of the intensity of the stimulus filling the time period judged was studied (as distinct from the background in the earlier three experiments). Frankenhauser concludes that "the intensity of the stimulus filling the interval had no marked influence on its subjective duration" (op. cit. pp. 80).

Similar results were obtained by Loeb (1957) working with 3–10 minutes intervals filled with noise up to 110 db. Banks and Cappon (1962) found that subjects underestimated 90 min. intervals when sensory input was reduced. They, however, simultaneously varied intensity and amount of change.

From her experiments, Frankenhauser draws the conclusion "that the rate of flow of mental events will influence the perception of time, whereas no support has been obtained for the assumption that the intensity of a constant stimulus would affect time perception". She ends by restricting her descriptive hypothetical construct of *amount of mental content* to *amount of mental events*. It may be noted that the intensity variation was kept within a small range of moderate intensity and that the condition where amount of change during the stimulus interval was tested was not carried through.

Hirsch, Bilger and Deatherage (1956) observes that apparent duration is dependent upon the level of auditory stimulation and is said to be independent of visual stimulation. They further reported that noise level—viz. an intensity variation—could have

an effect if this level is changed between the presentation and the reproduction.

Plutchik (1959) gives a broader review of this type of experimentation. He observes that recent evidence indicate that intermittent sound has both different and more disturbing effects than those of steady sound sources. Marked individual differences in susceptibility to effects of intermittent and steady noise are found. Plutchik observes that: "Individual differences in reaction to noise are extremely important to consider in evaluating research", (op. cit. pp. 136). He summarizes by stating (op. cit. pp. 148) "... recent experiments demonstrate effects of very loud sounds on certain kinds of complex behaviour particularly 'clockwatching' and time estimation with the possibility implied that the decrement in performance may depend on the level of the sound as well as on its intermittency ... The greatest effects are usually obtained at repetition rates between 5 and 10 pulses per second, a frequency range which coincides more or less closely with the alpha rhythm of the brain ... Some theoretical concepts are presented which postulate effects of auditory intermittency parallel to those of visual flicker." In conclusion Plutchik observes the need for more research.

4.6.3 *Comments*

The effects observed in experiments on subjective duration vary considerably with the conditions under which the auxiliary auditive stimulation is presented. Frankenhauser distinguishes on one hand between amount of change per time unit versus variation in the intensity of a constant stimulation, on the other hand between the above mentioned variations occurring in the background or as part of the stimulus figure.

The relevancy of the last distinction is not discussed. It was shown by Frankenhauser and others that intermittent auditive stimulation has an effect on subjective time estimation, but the role or meaningfulness of the distinction figure/background is unclear. If the effects encountered are of an intellectual or cogni-

tive type viz. the auxiliary stimulation functions as a basis for counting, the distinction figure/background may be relevant. If, however, the effects are sensoric viz. a result of e.g. reticular blocking or summation, the distinction may be meaningless.

The intermittency rate in the Frankenhauser experiments varies between 0.4 and 1.5 per second, i.e. very near the instructed rate of reading digits at one per second. The ability to count repetitive pulses seems to lie between 5 and 10 pulses per second (for a review see Plutchik op. cit. pp. 140). On the other hand the same effects were found for random frequency and constant frequency of sound pulses. Plutchik's conclusion that optimum effects are obtained around the frequency of the alpha rhythm and the observed similarity between auditory intermittency and visual flicker makes, however, simple conclusions impossible. Several investigations of sensory interaction on threshold- and supra-threshold levels generally have found marked effects when intensity of auxiliary stimulation was varied. Enough to say is that intermittent auditory pulses at least have an influence on subjective time estimates.

4.7 *Implications of Earlier Investigations for the Present Work*

The total picture of the studies reviewed in this chapter is apparently confusing. In almost no case the results from different investigations fall neatly into a line, not even when the same variables are manipulated. The vagueness of the concept sensory interaction is through differential application increased from the formulation of the concept in Chapter 2.

It may, however, be possible to set up a list of working hypothesis or rather, what Helson (1964) has called, subsumptions as a summary serving the purpose of guidelines for my own experiments.

I will, thus, restate my own aims with the experiments to be reported (see also Chapter 1) in order to link the subsumptions to the present work.

1. To study whether a specific type of sensory interaction effects —the influence of auditory stimulation on visual velocity percep-

tion and subjective time and distance as appearing in a geometrical illusion—could be measured by psychophysical scaling methods.

2. To study if data from the above mentioned experiments reveal anything beyond changes in the subjects' response-habits.

3. To study if the sensory interaction effects, if they are measurable by the technique mentioned above, are influenced by training or repetition of trials.

4.7.1 *Implications for subjective scaling*

As far as I know, subjective scaling has not been used in this type of experimentation.

a) Most of the earlier investigations have used classical psychophysical methods, most often the method of limits. One cause of the apparently contradictory results obtained may lay in a differential selection of points on the variables investigated. Scaling over a range of S-values may avoid part of that problem.

b) Several studies have shown that the effects vary with intensity and magnitude of the basic stimulation. The direction of the effect may be changes, inverted or disappear as stimuli are varied from intense to weak. Subjective scaling may reveal this functional relation.

c) A general observation is that the effects also seem to vary with intensity and magnitude of the auxiliary stimulation. Usually medium to strong auxiliary stimulation is necessary to elicit any effect.

d) The effect of intermittent auxiliary stimulation is usually greater than constant stimulation.

e) Temporal relations between basic and auxiliary stimulation are important. The strongest effects are usually observed when the auxiliary stimulation coincides with the basic stimulation.

f) The effects have a tendency to change with the duration of the stimulation time. Usually the strongest effects are observed when the stimulation time is 1 to 4 seconds. (This point also includes considerence of different labilizing techniques.) A fixed presentation time must be applied.

g) The effects may change with the repetition of trials. Either the effect disappears or a cumulative effect is observed. Sensory conditioning may occur. This indicates that data ought to be analyzed in the sequence they were collected.

h) Some indicate ought to be possible to get by subjective scaling concerning the relation between sensitivity and reactivity viz. the differential reaction on threshold and supra threshold stimuli.

i) The problem of consonancy, viz. if both auxiliary and basic stimulation possesses the same attribute, does the subject judge the same attribute in both types of stimulation or in the combined stimulus pattern, might be able to study by e.g. factor analysis of subjective scale values.

j) Considerence of the important role played by instruction and set.

k) The generally observed differential individual susceptibility to sensory interaction effects indicates that individual data primarily should be analysed. Group data should be interpreted with caution.

l) There is some evidence that female subjects may be more susceptible to sensory interaction effects than male subjects. Data from the two sexes should thus be analysed separately.

4.7.2 *Implications for the problem of response-bias*

The question whether the sensory interaction effects observed may be described as some kind of response-bias has been treated by varying variables such as instruction, set, judgemental language. Variation of these variables usually has an effect, often found superimposed on the effects of S-variables. In studies where they are not analysed separately, one could not rule out their impact entirely. Few studies are found where sensory interaction effects have been measured through different methods in the same experiment. The implications may be summarized thus:

a) The instructions should be formalized and kept constant through a whole experiment.

b) The experimentor should preferably not know about the effects expected.

c) The same effects should preferably be measured by using different psychophysical methods including such which allow for a minimum of verbal response differentiation.

d) The possibility of a differential individual susceptibility to response-bias must be noticed.

e) Secondary effects, i.e. casual integration may be found.

4.7.3. *Implications for the problem of training and repetition effects*

Data indicating training and repetition effects are to be found in experiments on sensory conditioning, distorted cues and spatial localization. Training effects and primarily repetition effects are difficult to distinguish from effects on one hand due to response-bias on the other hand due to stimulation duration.

The training effects found are sometimes not retained from day to day, sometimes a cumulative effect is observed. In general the main change occurs during the first few trials, usually as a disappearance of the effects.

The implications of this evidence for my own experiments may be summarized:

a) Data from different trials ought to be analysed separately.

b) The same subject may not be used in a sequence of experiments. If he is used in such a way, it must be observed that the effects studied may change or disappear altogether.

c) The stimulation time in each trial must be kept constant and under control.

d) Pre-experimental trials should be used with caution.

Chapter 5

Subsumptions[1] and working hypothesis

5.1 *Introduction*

The experiments to be reported and discussed in the following must be considered as exploratory. There are two main reasons for this—both have been mentioned in the foregoing four chapters. Firstly, the results of earlier investigations are highly ambiguous and do not lend themselves to any simple explanations, and secondly the number of investigations directly relevant for the specific stimulus variables used—velocity and real motion—are few.

The main part of this study deals with velocity perception. It is not the velocity *per se* which is being investigated. Velocity is used as a suitable carrier-variable on which to study the effect of intermittent auditive stimulation.

In most of the experiments subjective scaling methods are used. The primary interest lies not in the scaling methods as such, but rather in the possibility of using them as techniques to study sensory interaction effects of the type mentioned above.

Problems of velocity perception and methodological questions will thus be dealt with only when they are relevant for the phenomenon in sensory interaction effects.

In the exploratory approach chosen attention is focussed on problem detection rather than on providing answers to questions or hypothesis testing. Against this may be argued that an investigation would win more in the way of coherence if a more specific point of departure had been chosen. The main reason for not choosing this

[1] *Subsumption* is used here in the sense defined by Helson (1964) p. 8: "When a fact or a class of facts is shown to be a member of a larger class with which it has something in common, we may say it is *subsumed* under the larger class. Even though the larger class of facts may not be fully understood, subsumption of isolated facts often helps to direct thinking into the proper channels." See also section 4.7.

latter approach is the results from the preliminary experiments showing that even the isolating and measuring of any sensory interaction effect is quite a cumbersome task in itself.

5.2 *Origin of the present studies*

The original idea initiating this work comes from the experiment by Johansson (op. cit.) reviewed and discussed in Chapter 4. A first preliminary experiment was performed as a modified replication of the Johansson experiment,—(Ottander 1956). In a factorial design 4 velocities and 3 auditive intermittent frequencies were combined. 15 subjects used the method of reproduction and subjectively equalized a "silent" velocity and a velocity "loaded" with an intermittent tone of 800 cps. No significant sensory interaction effects were found when group data were analysed.

The display presenting the velocities to be judged consisted of a dotted circular pattern. It was observed that this pattern induced a strong motion after-effect. It is possible that this phenomenon may have disrupted the sensory interaction effects. The experiment did however expose a nonsignificant tendency in the same direction as that reported by Johansson.

A difference between the original experiment by Johansson and the present one is that his subjects compared two velocities "loaded" with different auditive intermittent frequencies, while in this experiment the comparison took place between "silent" or a zero-loaded velocity and a "loaded" velocity. It may thus be possible that the effect found by Johansson depends on one velocity being depressed and the other being enhanced by the auditive intermittent frequency. This interpretation implies that different intermittent frequencies yield differential effects as to size and direction. The total effect found by Johansson was ca. 7 % "overestimation" of the loaded velocity relative the less loaded velocity.

At the start of the present work the following experimental data were at hand:

1. A mass of data, difficult to interpret from sensory interaction experiments, mostly studying threshold changes as an effect of

intermodal interaction. The direction of the effects does not seem to follow any clear cut or simple rules.
2. Two experiments of auditory interaction effects on visual velocity, one positive and one more or less negative.

The main problem for the present series of experiment is thus to determine whether auditory auxiliary stimulation in any way influences the judgement of visual velocity.

5.3 *Subsumptions and disposition of experiments*

5.3.1 *Principal subsumptions*

Six principal subsumptions are made for the present series of experiments:

1. Sensory interaction effects are found when an auditive intermittent tone is presented simultaneously with a visually seen velocity.
2. Differential effects do occur when the intermittent tone is presented together with different velocities.
3. A differential effect of different intermittent frequencies is found when the same set of velocities are judged with different intermittent frequencies.
4. These effects can be measured with subjective scaling methods (ratio estimation, magnitude estimation and paired comparisons).
5. There is a differential individual susceptibility to sensory interaction effects.
6. The effect changes in a systematic way over judgement instances.

These principal subsumptions are studied and specified throughout the series of experiments.

5.3.2 *A disposition of the experimental work and problems encountered*

In Chapter 6, Experiments I and II (ratio estimation of silent and loaded velocity) give preliminary working hypotheses as regards

the six subsumptions. In addition three new questions are stated:

7. Is the sensory interaction effect found an artifact of the method of measurement and the judgemental language used?
8. Are the response-matrices internally consistent?
9. Are the response-matrices unidimensional?

In Chapter 7, Experiments III, IV, V and VI (magnitude estimation of silent and loaded velocity) provide further information about the main subsumptions and questions 7 and 9. Taken together with the results from Experiment I and II the results from these four experiments support subsumptions 1 and 2 and partly support subsumption 4 and 6; subsumption 3 is contradicted and subsumption 5 remains unanswered. Additional problems encountered are:

10. The effect of the method of measurement, perhaps superimposed on the effect of sensory interaction.
11. The effect of the position of the standard when using the method of magnitude estimation.

In Chapter 8, Experiments VII, VIII, IX and X (ratio estimation of silent and loaded velocity and auditive intermittent frequency) the subsumptions and the problems stated under 1–9 are further studied. Specifically questions 8 and 9 about the internal consistency and the dimensionality of the response-matrices are studied. In these experiments group data prove to be internally consistent and unidimensional. New problems are:

12. The possible effect of the unit of measurement chosen in each experiment.
13. The adequacy of the data model, previously stated.

Chapter 9, Experiment XI (ratio estimation of silent and loaded velocity) studies the problems of internal consistency and dimensionality (8 and 9) on the individual response-matrix level. The findings from Chapter 8 are verified. An attempt is made to resolve question 12 which is treated as being linked to question 13. An alternative data model is proposed. The combined body of data so far answers questions 1, 2, 4 (in part), 6, 8 and 9 positively. Subsumptions 3 and 5 are contradicted while questions 7, 10, 11

and 12 remain unresolved and a tentative solution is given to question 13.

In Chapter 10, four experiments (XII, XIII, XIV and XV) are reported. Two of them, XII and XIII are paired comparisons of silent and loaded velocity and silent and loaded time respectively and the results from these experiments are positive for subsumptions 4 and 6.

The remaining two experiments in this chapter, XIV and XV are demonstrations by analogy of how the methods of ratio estimation and paired comparisons function in measuring the well established phenomenon of the Müller-Lyer illusion. Distances with and without the illusion are judged according to the two methods, the stimuli-setting being an example of unidimensional sensory interaction.

The demonstration serves two purposes: a) It gives a set of data which can be compared with data arrived at through classical psychophysical methods. b) It gives data usable as a basis for an indirect estimation of the relative size and direction of the auditive sensory interaction effects measured in terms of estimates of subjective velocity.

Experiment XV is run over ten days, with and without monetary reinforcement, giving a broader base to discuss the changes over judgement instances first noticed in Chapter 6 and stated in subsumption 6. A systematic change is noticed also in the Müller-Lyer experiment and the somewhat surprising finding is that the illusion does not disappear but oscillates in a pattern resembling that found earlier with subjective velocity and time. No explanation could be given.

In Chapter 11 four experiments, XVI, XVII, XVIII and XIX are reported. Two of them are similarity matchings of auditive and visual intermittent frequency and silent velocity. The last two experiments are ratio scaling of auditively loaded and visually loaded velocity and silent velocity. In these four experiments the comparison between intermodal and unimodal conditions is made more directly: the intermittent frequency is given auditively and visually.

The matching experiments are an indirect test of the found

internal consistency and unidimensionality of individual response-matrices. If subjects can give ratio estimates they ought to be able to match intermittent frequency and visual velocity. The results indicate that subjects find their task easy but that they show an extreme variation in their responses.

Experiments XVIII and XIX are ratio scaling of auditively and visually loaded velocity and silent velocity. The same type of effect is found irrespective of how the intermittent frequency is presented. The visually presented frequency seems to have a greater influence than that presented auditively.

In Chapter 12 the findings from this series of experiments are discussed in relation to the different theoretical standpoints concerning sensory interaction.

5.3.3 *Individual- and/or group-analysis of data*

It is pointed out in 4.7.1 and 5.3.1 that individuals may be differentially susceptible to sensory interaction effects. As a precaution against this all data are treated on an individual level before group analysis are carried out. The reader is forewarned that because of this the forthcoming chapters are burdened with lengthy tables and diagrams.

Group scales and curves serve mainly illustrative purposes and are taken as a basis for discussion as long as the tendencies and patterns they reveal could also be found on the individual level.

An attempt to describe the effect of sensory interaction in terms of differences in parameters of the psychophysical power function

$$R = c\,(S-So)^n$$

is made in Chapter 8 and Appendix II but finally abandoned for the abovementioned reason. The specific reasons are given in Appendix II.

5.4 *Experimentors and subjects*

A number of the studies on sensory interaction reviewed in Chapter 4 suggest that it is very easy to induce sensory interaction effects

in the direction assumed (or desired) by implicit or explicit suggestion. As a precaution against these possible effects two strategies have been pursued:

a) The experimentors have been kept in ignorance of the direction of the effects expected in the experiments they have led.
b) Subjects have for the most part been used in only one series of experiments and their questions concerning the purpose of the experiments have not been answered until after the sessions.

In view of point a) the author has not served as experimentor in any experiment (except for the preliminary one briefly reviewed in 5.2. Four different experimentors have carried out the present experiments independent of each other.

Experimentor 1 served in Experiments I–IV, Experimentor 2 served in Experiments VII–X, Experimentor 3 served in Experiments XI–XV and Experimentor 4 served in Experiments XVI–XIX.

The four experimentors have used different laboratories for their experiments.

The subjects used have for the most part been undergraduate students of psychology. All of these have had a working knowledge of experimental work and scaling methods. The results from these subjects did not differ from those of subjects who had not studied psychology. These latter subjects participated in Experiments VIII–X and XVI–XIX.

Except for Experiments XV and XVI–XIX the subjects participated voluntarily. In the former five experiments mentioned the subjects were paid.

Of the participating subjects none have been excluded from the numerical analysis unless specifically stated in the text.

5.5 *Pre-trials, instructions and rest-pauses*

5.5.1 *Pre-trials*

Because of reasons given in 4.7.1 pre-trials have not been used in any of the present experiments. So long as students of psychology have served as subjects this has functioned well as all of them had

a general knowledge of the methods used. For those subjects not aquainted with experimental psychology, a brief explanation of the methods was given, using size and form of simple geometrical figures as examples. No subject reported difficulties in understanding and carrying out the tasks.

5.5.2 *Instructions*

Instructions are kept as brief as possible and are as a rule pretested on subjects not participating in the experiments proper. In the series of experiment to be reported five methods of measurement are used:

1) generalized ratio estimation (see Ekman 1958)
2) magnitude estimation
3) paired comparisons
4) the method of limits
5) the method of reproduction (similarity matchings)

The instructions for these methods were as follows (exceptions to the instructions given below are noted in the text):

1. Generalized ratio estimation.
   "Give the relation between these two speeds (times, distances) in percent. Use the speed (time, distance) presented first (second) as a reference stimulus."
2. Magnitude estimation.
   The standard stimulus is presented for ca. 60 seconds. "This speed is called 10. Give a number to all other speeds to be presented which relates them to this standard speed which is called 10."
3. Paired comparisons.
   "Indicate by saying, presented first or presented second, which of the two speeds (times, distances) to be presented is fastest (longest)."
4. The method of limits.
   "Indicate at each presentation whether the two distances presented are equal or which of them is longest."

5. The method of reproduction. (Similarity matchings.)
"Adjust the speed so that it is equal to the interrupted sound (interrupted light)."

During an experimental session pauses between trials were as short as the equipment allowed. As a rule no rest-pauses were allowed and each session was thus run in one sequence.

Complaints were recorded only in Experiment XI (Chapter 9) where each session lasted between $1\frac{1}{2}$–2 hours.

Chapter 6

Two preliminary experiments on ratio estimation of subjective velocity versus velocity loaded with intermittent auditive auxiliary stimulation

6.1 *Choice of experimental conditions*

In these experiments a *silent* and an auditively *loaded* velocity are compared. The working hypothesis is that the auditively loaded velocity is subjectively perceived as being greater than the corresponding silent velocity. The auditive stimulation is conditional to the velocity in the sense that it appears simultaneously with it, i.e. it is part of the stimulus figure. It is, however, given auditively and the intermittent frequency does not coincide with the frequency of the visually presented motion in any case.

Six angular velocities were selected for study:

	20	36	60	90	113	153	revs. per minute (r.p.m.)
or	0.33	0.60	1.00	1.50	1.88	2.55	revs. per second (r.p.s.)
or	24	43.2	72	108	135.6	183.6	cm/sec.

In the following r.p.m. will be the unit used throughout unless otherwise stated.

The reasons for choosing this set of velocities were briefly the following. I wanted velocities within and above the range where eye-movement pursuit of the motion was possible. Using an eye movement camera, (Johansson and Backlund (1960)), the subjects' ability to follow the motion with their eyes showed that they could easily follow a motion of 20 r.p.m. but not a motion over

140 r.p.m. The subjects did not, however, show any clear threshold level where this ability broke down. Around 40 r.p.m. they started to follow the motion with the amplitude of the eye-movements gradually decreasing as compared to the objective amplitude. In other words they "cheated" by following the motion inside the actual motion track[1]. This decrease of amplitude continued up to around 130 r.p.m. At 130 r.p.m. pursuit became intermittent and over 140 r.p.m. no pursuit occurred at all. An interindividual variability in pursuit ability was noticed.

The extreme velocities were determined on the basis of these findings. Originally a semi-logarithmic series consisting of 20, 40, 60, 90, 120 and 160 r.p.m. was chosen. The exact values given above are empirical determinations of the commercial equipment.

In Experiment I an intermittency frequency of 12 per second is used and in Experiment II this frequency is 5 per second. The sound is a pure tone of 800 cps. The tone pulses are rectangular and the on-off ratio is 1:1. The loudness is measured and kept constant at a subjectively "loud" level (82.5 db) thus being below the pain threshold. This loudness level was described as unpleasant by most subjects.

The reason for choosing this combination is the following. The tone of 800 cps was chosen to be able to compare the results with those of Johansson (op. cit.). The intermittency frequencies of 12 and 5 per second were chosen on the grounds that these were not of the same frequency as any of the stimulus velocities used. Further, one of the frequencies is clearly above the counting ability of human observers and the other clearly within this ability, see e.g. Plutchik (op. cit. pp. 141) and Békésy (1957).

In both experiments the generalized ratio scaling method of Ekman (1958) was used. Ekman starts with the model $q_{ij} = \mathrm{Ri/Rj}$. With this method and model it is possible to get scale-values on both silent and loaded velocity in the same experimental session

[1] The observed "inside tracking" bears a curious resemblance to the shrinkage of circular motion observed by Brown and Voth (1937) when velocity of circular motion is increased. Brown and Voth give an elegant Gestalt-theoretical description of this phenomenon. These incidental findings suggest that the shrinkage may be related to the decrease in eye-movement amplitude.

and in the same scale-unit, i.e. the two scales are comparable. (This is in fact not completely true as one of the basic S-scales is a combined scale of visual *and* auditive stimulation and the other does not contain the auditive component. A comparison in e.g. a R-S-diagram may thus be misleading. This point will, however, be taken up in a later paragraph.) The same subjects participated in both experiments. The experiments were carried out on separate days. The order of the experiments was random.

6.2 *Experiment I*

6.2.1 *Procedure*

Seven subjects (4 male, 3 female, age 20–24 years) were run using the generalized ratio scaling method (Ekman, ibid.). The velocities used were 20, 36, 60, 90, 113 and 153 r.p.m. Each velocity was displayed as a light spot (diam. 4 mm) moving on a screen in a circular track (diam. 12 cm). The two velocities in each pair appeared side by side on the screen, one being silent and the other loaded. They could not be seen simultaneously. The position of the loaded velocity was randomly varied in right and left position. The apparatus is described in detail in Appendix 1. The intermittent tone (800 cps, 12 sounds per second, 82.5 db) was presented through headphones. The subject was seated 1.5 meters from the screen. The experimental room was kept in semidarkness during sessions. The subject was allowed to switch between the silent and the loaded velocity as often as he wished. Each combination of 36 pairs of velocities was judged 4 times (in all 144 judgements per subject) the order of presentation, right left position and silent or loaded presented first being randomized. The subject was allowed to use only ratios $\leqq 1.00$ if he wanted that. (Four of the subjects were given Exp. I first, the other three started with Exp. II.)

6.2.2 *Results*

The artihmetic means and the geometric means in each cell were computed. The scale values for silent velocity were computed as

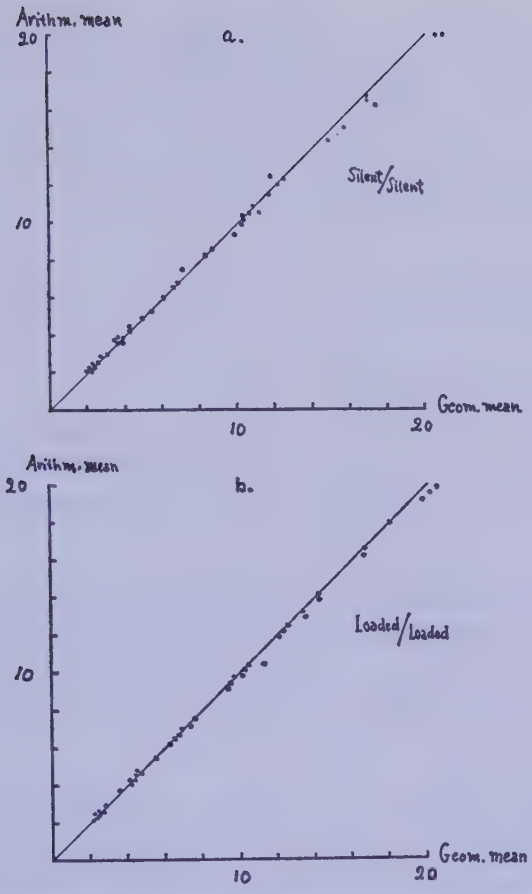


Diagram 6.1 Experiment 1. Plots between scales computed with geometric means and arithmetic means within cells.
a. Silent scales. b. Loaded scales.
(Not included in a. 46.35/44.42; in b. 31.41/30.16.)

$$R_{si} = \Sigma_{ri}$$

Separate computations were made for the two types of means. The scale values for loaded velocity were computed as

$$R_{lj} = \frac{T_{..}}{\Sigma_{cj}}$$

Where R_{si} and R_{lj} are the scale values for silent and loaded velocity respectively, Σ_{ri} is the sum of row i, Σ_{cj} is the sum of column j and $T\,.\,.$ is the total sum of the matrix.

In Table 6.1 a and b individual scale values on silent and loaded velocity respectively are given. (Subject 5 deviates from the rest of the group. As the deviation is one of magnitude rather than random fluctuations she is included in all group mean calculations. A control test using conventional ratio scaling on silent velocity only showed that subject 5 also in this case gave high scale values on velocities 113 and 153 r.p.m. The difference between the row and column scales was smaller however, and the direction of the difference was reversed.)

In Diagram 6.1 a and b scales computed on arithmetic means and geometric means are compared. As seen the difference between the scales is small. In the following scale-values on geometric means are used if not otherwise stated.

In Diagram 6.2 plots of the relation between silent and loaded mean individual scale values are given. In Table 6.2 the difference between the individual loaded scale values and the corresponding silent scale values are given together with the mean differences and these latter are also given as a percent of the mean silent scale values. These mean differences are graphically represented in Diagram 6.3 a and b.

In Table 6.3 a and b are given mean scale values for the first, fourth and all four estimates. In Table 6.3 c are given the mean ratios in the diagonal, i.e. ratios from objectively equal velocities.

The subjects reported in addition a causal integration phenomena, where the intermittent auditive stimulation was "heard" in the ear corresponding to the side where the loaded velocity was presented. (Naturally both ears were stimulated alike.)

6.3 *Experiment II*

6.3.1 *Procedure*

The same subjects (n = 7) as in Exp. I participated. Experiment II was run in the same way as Exp. I with the difference that the

Table 6.1

a) Experiment I. Individual scale values calculated with geometric means of each matrix cell. Silent velocity. (Notations after subject number, m = male, f = female.)

	20	36	60	90	113	153	r.p.m.
Subject No.							
1 m	2.43	3.86	6.79	10.97	11.85	17.00	
2 m	2.27	4.26	8.36	10.42	12.29	20.79	
3 m	2.63	3.90	6.10	8.72	11.77	15.82	
4 m	2.34	3.90	7.10	10.41	12.57	17.53	
5 f	2.14	3.78	5.58	10.26	17.00	46.35	
6 f	3.04	4.33	6.67	9.87	11.24	14.81	
7 f	2.77	3.78	4.95	8.24	10.67	21.07	
Mean	2.52	3.97	6.51	9.84	12.48	21.91	

b) Experiment I. Individual scale values calculated with geometric means of each matrix cell. Loaded velocity. Intermittency frequency 12 per second.

	20	36	60	90	113	153	r.p.m.
Subject No.							
1 m	2.56	4.13	6.98	9.72	12.54	18.05	
2 m	2.36	4.74	6.70	10.33	14.38	19.86	
3 m	2.64	4.49	6.58	9.56	12.11	16.70	
4 m	2.38	4.53	7.73	10.54	13.40	16.72	
5 f	2.39	3.67	6.30	14.38	20.71	31.41	
6 f	2.59	4.59	7.31	10.22	11.46	13.54	
7 f	2.76	4.41	5.69	9.41	12.46	20.59	
Mean	2.53	4.37	6.76	10.59	13.87	19.55	

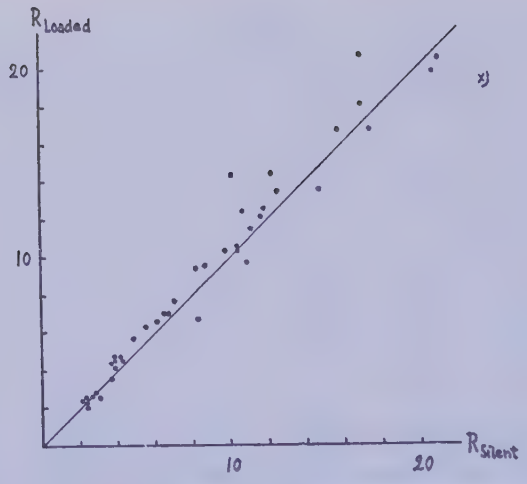


Diagram 6.2 Experiment I. Plot of the relation between silent and loaded scale values. Number of subjects = 7.
*) One pair of values for Subject 5 on 153 r.p.m. (46.35/31.41) is not in the diagram.

Table 6.2

Experiment I, calculated with geometric means in each matrix cell. Differences between loaded and silent individual scale values. $\overline{\text{Diff.}}$ = the mean of these differences. $\overline{\text{Diff.}}$ % = $\overline{\text{Diff.}}$ given in percent of the group mean silent scale value.

	20	36	60	90	113	153 r.p.m.
Subject No.						
1 m	0.13	0.27	0.19	—1.25	0.69	1.05
2 m	0.09	0.48	0.34	—0.09	2.09	—0.93
3 m	0.01	0.59	0.48	0.84	0.34	—0.88
4 m	0.04	0.63	0.63	0.13	0.83	0.81
5 f	0.25	—0.11	0.72	4.12	3.71	—14.94
6 f	—0.45	0.26	0.64	0.35	0.22	—1.27
7 f	—0.01	0.63	0.74	1.17	1.79	—0.48
$\overline{\text{Diff.}}$	0.01	0.39	0.53	0.75	1.38	—2.38
$\overline{\text{Diff.}}$ %	0.40	9.82	8.14	7.62	11.06	—10.86

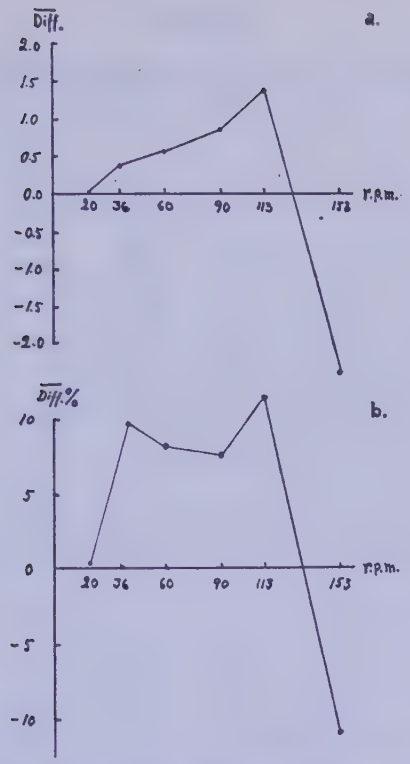


Diagram 6.3 Experiment I, intermittent frequency 12 per second.
a. Compared velocities plotted against mean difference between loaded and silent scale values ($\overline{\text{Diff.}}$). b. $\overline{\text{Diff.}}$ given in percent of corresponding silent scale value (Diff. %).

intermittency frequency here was 5 per second (as compared to 12 per second in Exp. I).

6.3.2 *Results*

The arithmetic means and geometric means in each cell were computed as before. In Table 6.4 a and b scale values on silent and loaded velocity are given. (Subject 5 exhibits the same deviation from the rest of the group as shown in Exp. I.)

Table 6.3

a) Mean scale value for 1:st estimate, 4:th estimate and all 4 estimates. Silent velocity, 7 subjects.

	20	36	60	90	113	153	r.p.m.
1:st est.	2.43	3.73	6.91	10.94	12.68	22.54	
4:th est.	2.62	4.13	6.47	10.14	12.93	23.33	
all 4 est.	2.56	4.01	6.50	9.68	12.29	21.14	

b) Mean scale value for 1:st estimate, 4:th estimate and all 4 estimates. Loaded velocity (12 per second), 7 subjects.

	20	36	60	90	113	153	r.p.m.
1:st est.	2.46	4.17	6.84	11.64	14.14	19.81	
4:th est.	2.56	4.10	6.54	10.63	14.58	20.21	
all 4 est.	2.55	4.45	6.71	10.40	13.44	18.92	

c) Mean diagonal cell ratios. Silent velocity in percent of loaded velocity (12 per second), 7 subjects.

20	36	60	90	113	153	r.p.m.
98.71	95.43	96.57	98.28	96.43	97.28	

In Diagram 6.4 a and b are given the plots between scales computed from arithmetic and geometric means.

In Diagram 6.5 plots of the relation between silent and loaded mean individual scale values are given. In Table 6.5 the difference between the individual loaded scale values and the corresponding silent scale values are given together with the mean differences and these latter are also given as a percent of the mean silent scale value. These mean differences are graphically represented in Diagram 6.6 a and b.

In Table 6.6 are given the mean cell ratios from the diagonal of the group matrix, viz. the comparison of objectively equal velocities. The same causal integration phenomena as mentioned in Exp. I was noted.

Table 6.4

a) Experiment II. Individual scale values from the generalized ratio scaling method, geometric means. Silent velocity. (Notations after subject number, m = male, f = female.)

Subject No.	20	36	60	90	113	153	r.p.m.
1 m	2.34	4.18	6.78	9.47	11.59	17.19	
2 m	2.34	4.47	7.25	9.92	15.53	17.85	
3 m	1.22	3.72	7.58	11.27	12.07	17.34	
4 m	2.12	3.96	7.58	11.35	14.72	23.46	
5 f	2.34	3.94	6.31	10.87	16.96	42.00	
6 f	2.69	4.12	7.61	10.99	14.19	18.00	
7 f	3.06	4.42	5.70	8.98	11.96	17.94	
Arithmetic mean	2.30	4.12	6.97	10.41	13.86	21.97	

b) Individual scale values from the generalized ratio scaling method, geometric means. Loaded velocity, intermittent frequency 5 per second.

Subject No.	20	36	60	90	113	153	r.p.m.
1 m	2.56	4.58	6.74	9.51	12.35	17.57	
2 m	2.40	4.52	6.69	11.18	14.14	18.97	
3 m	2.54	4.05	6.91	10.53	13.85	21.36	
4 m	2.39	4.00	7.76	10.96	14.76	22.94	
5 f	2.26	4.08	6.19	15.01	19.79	28.96	
6 f	2.42	4.60	7.12	10.82	12.70	17.24	
7 f	2.86	3.96	6.69	8.85	12.34	18.19	
Arithmetic mean	2.49	4.26	6.87	10.98	14.28	20.75	

6.4 *Discussion of the results from Experiments I and II*

The two experiments used the same method, the generalized ratio scaling method, and the same subjects but different intermittent auditive stimulation (12 and 5 per second) and were carried out on different days. A subject was allowed to see (and hear) each stimuli combination as often, or for as long, as he or she desired.

The results are not easy to interpret. The effect of the intermittent auditive stimulation is hard to determine. As a working hypothesis I expected that a loaded velocity should be over-

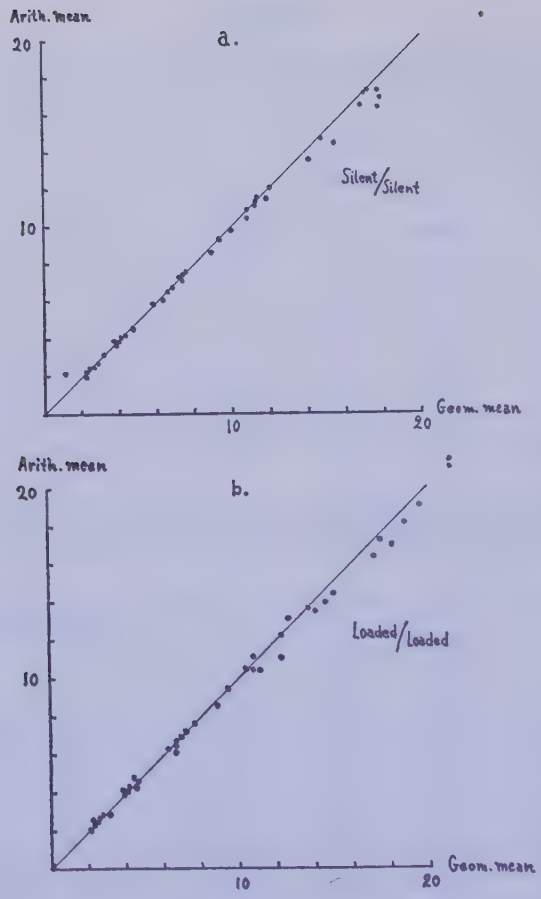


Diagram 6.4 Experiment II. Plots between scales computed with geometric means and arithmetic means within cells.
a. Silent scales. b. Loaded scales.
(Not included in a. 42.00/40.90; in b. 28.96/27.53.)

estimated (as compared to a silent velocity), and that this phenomenon could be measured by subjective ratio scaling. The effect—if there is any—appears to go in different directions for different velocities in both experiments (see Tables 6.1, 6.2, 6.4, 6.5 and Diagrams 6.3 and 6.5). Both experiments show however, bimodal effect curves. Smaller negative effects for low and high velocities

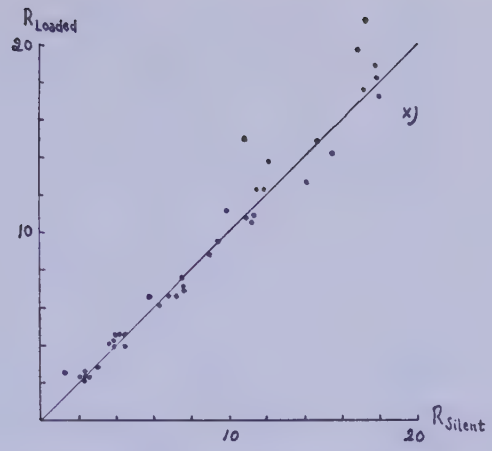


Diagram 6.5 Experiment II. Plot of the relation between silent and loaded scale values. Number of subjetcs = 7.
*) One pair of values for Subject 5 on 153 r.p.m. (42.00/28.96) is not in the diagram.

Table 6.5

Experiment II. Intermittent frequency 5 per second.
Difference between loaded and silent scale value for each subject.
$\overline{\text{Diff.}}$ = mean difference computed over 7 subjects.
$\overline{\text{Diff.}}$ % is this mean difference given in percent of the corresponding mean silent scale value.

Subject No.	20	36	60	90	113	153 r.p.m.
1 m	0.22	0.40	—0.04	0.04	0.76	0.38
2 m	0.07	0.05	—0.56	1.26	—1.39	1.12
3 m	1.32	0.33	—0.67	—0.74	1.78	4.02
4 m	0.27	0.04	0.18	—0.39	0.04	—0.52
5 f	—0.08	0.14	—0.12	4.14	2.83	—13.04
6 f	—0.27	0.48	—0.49	—0.17	—1.49	—0.76
7 f	—0.20	—0.46	0.99	—0.13	0.38	0.25
$\overline{\text{Diff.}}$	0.19	0.14	—0.11	0.57	0.42	—1.22
$\overline{\text{Diff.}}$ %	8.26	3.40	—1.58	5.48	3.03	—5.55

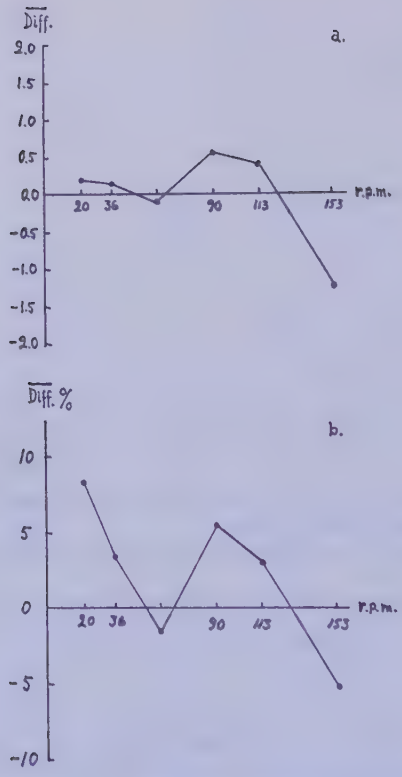


Diagram 6.6 Experiment II, intermittent frequency 5 per second.
a. Compared velocities plotted against mean difference between loaded and silent scale values, (Diff.). b. Diff. given in percent of corresponding mean silent scale value.

Table 6.6

Mean diagonal cell ratios. Silent velocity in percent of loaded velocity (5 per second), 7 subjects.

20	36	60	90	113	153	r.p.m.
96.00	96.89	95.07	99.18	94.78	96.50	

and a dip in the curves at an intermediate velocity. It would seem natural to consider this intermediate dip an effect of random variation but as five of seven subjects show this bimodality in Exp. I and all seven in Exp. II, it may be worth noting. At this stage it is unclear whether the effect changes observed are random variations, artifacts of the method of measurement used, caused by the intermittent frequencies, or an interaction between the last two factors. I would venture a tentative guess that it lies in the method of ratio scaling used. Still, the deviations go in the direction predicted by the hypothesis at four out of the six points measured in both experiments. The plots of silent versus loaded scale values show a slight positive deviation from the zero-effect 45° line (see Diagrams 6.2 and 6.5), this tendency being slightly smaller in Exp. II (Diagram 6.5). It is, however, hard to determine whether this deviation depends on a sensory interaction effect or on an inconsistency within the response matrices. (This question will be discussed further in Chapters 8 and 9.)

Another possibility is that the data model suggested by Ekman (ibid.) and used here, namely $q_{ij} = R_i/R_j$ is erroneous. For the conventional ratio scaling method at least two alternative models have been proposed. Eisler (1960) suggested $q_{ij} = k(R_i/R_j)$ according to which a constant k is multiplied to a given response matrix. This model does not seem to fit our results. Another model is suggested by Goude (1962) and Sjöberg (1965). This model implies the existence of an effect on the subjective value of a stimulus depending on whether it occurs as standard or as variable in a given comparison, and may be written $q_{ij} = R_{i,v}/R_{j,s}$. $R_{i,v}$ is the subjective value of stimulus i when it occurs as variable and $R_{j,s}$ is the subjective value of stimulus j when it occurs as standard.

In our case the model is complicated by the fact the generalized ratio scaling method is used applying nonidentical stimuli as variable and standard stimuli sets.

If the Goude-Sjöberg model is adapted to our general case, our findings may be described in either of two ways: one assuming a nonexistent interactional effect and a variable/standard effect, the other assuming the existence of both the interactional effect and a variable/standard effect. If the first case is true our relative

difference curves have nothing to do with sensory interaction. This statement is however indirectly disproved by the result earlier cited from Johansson (ibid.) using another technique. If the second case is true the relative difference curves do show a pooled effect of sensory interaction and variable/standard. The influence of a variable/standard effect could indirectly be studied by switching the sets functioning as variable and standard stimuli. This line will be carried on in Chapter 8. An alternative approach is to try to control and if possible eliminate the effect of variable/standard from the sensory interaction effect. This will be attempted and discussed in Chapter 9.

The magnitude of the effect expressed as a percentage (maximum 11 %) is comparable to that found by Johansson (ibid.), his being about 7 %. A further comparison with Johansson's results is possible. From Tables 6.3 c and 6.6 is seen that a silent velocity is underestimated when compared to an objectively equal but loaded velocity—irrespective of the intermittency frequency.

It is, however, still dubious whether the effect found is greater (or more systematic) than a random variation. Significance testing is, because of conditionality within data, impossible.

The logical thing to do would have been to let the subjects go through a control condition, scaling only silent velocity, and compare this (e.g. the scale difference found between rows and columns) to the difference found here. There are two reasons for not doing this: a) Two experimental sessions would be needed and b) The expected repetition effect mentioned in Chapter 4 may make such a comparison meaningless. (A further discussion of these points will be given in Chapter 7 and 8.) If scales from the first, second, third and fourth estimation simply are summed, the sum is largest at the first and fourth estimation, smaller at the second and third. This may tentatively be taken as indicating that the effect changes over trials so that it is largest at the start.

I have compared the scale values from the first and fourth estimate for both the silent and the loaded condition in Exp. I (see Table 6.3 a and b). Similar results appeared in Exp. II. These scale differences are slighty smaller and do not show the regular pattern seen in Diagrams 6.3 and 6.6.

In general, the intermittency frequency of 5 per second seems to yield similar (but slightly smaller) effects than does 12 per second. The small difference in effect between 5 and 12 tones per second is unexpected in the light of Frankenhauser's (ibid.) experiments on subjective time discussed in chapter 4. She found marked differences between high and low intermittent frequencies on time estimates.

No marked differential individual susceptibility to intermittent auditive stimulation is apparent. The experiments described raise more questions than they answer. Weak support is given for a sensory interaction effect. Apparently ratio-scaling measures this effect. Is the effect found greater than random variation? What is the role played by inconsistency in the ratio matrices? Is the data model assumed inadequate? How does the unlimited time allowed for each estimation affect the results? Can the weak evidence given for a change of effect with repetition of trials be verified? These are some of the questions to be dealt with in the forthcoming experiments.

Chapter 7

Four experiments on magnitude estimation of silent and loaded velocity

7.1 *Problems and experimental conditions*

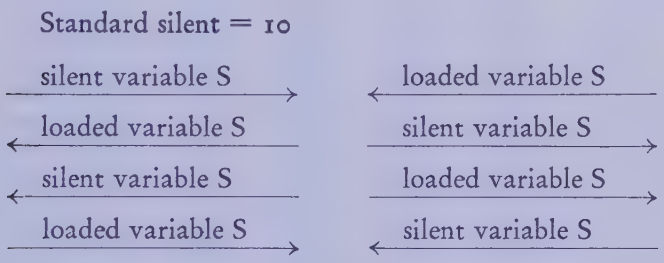
These experiments deal with the subjective estimation of silent and loaded velocities. The working hypothesis is that loaded velocity will be over-estimated as compared to a silent velocity and that this over-estimation can be measured by the method of magnitude estimation. The general set-up used in these experiments is identical with the one used in Exp. I and II except that in this case the stimulus presentation was managed by the experimenter, (see Appendix 1).

As the effect under study is very weak, certain modifications in the method of magnitude estimation were made. Ideally, estimates of both silent and loaded velocity should be obtained from the same judgement instance but this is obviously impossible with the method of magnitude estimation. What I can do, is to set up a situation knowing that the reference point and the unit in the estimation procedure are functions of that particular experimental situation, but where both silent and loaded estimates are given. The procedure chosen could be described thus. The subject was presented a silent standard velocity (60 or 113 r.p.m.) for 1 minute and told that this velocity was called 10. He was instructed to judge all the other velocities presented to him (silent and loaded) in relation to this standard. Each estimate was based on the following sequence:

Standard	Variable stimulus	Standard
5 seconds	5 seconds	5 seconds

The interval between each 5 seconds presentation was a fraction of a second, the time taken to switch between two stimuli. It is thought that time order errors are balanced by this procedure, or at least do not go in the same direction as the effect under study.

An experimental session ran as is schematically described below. The main reason for choosing this up-and-down procedure was that a random presentation of the variable velocities would have led to very long interjudgement intervals caused by constructional features in the apparatus.



This procedure may induce number habits and give rise to hysteresis effects. These drawbacks will be borne in mind and will be further discussed in Chapter 9. It is thought that the order of presentation employed balances at least the hysteresis effect. Thus, each subject gives four estimates on each silent and loaded velocity.

Experiments III and IV used an intermittent frequency of 12 per second, Experiments V and VI used 5 per second. (Tone 800 cps, loudness 82.5 db constant and high, as in Exp. I and II.) In Exp. III and V the standard was silent 60 r.p.m., in Exp. IV and VI silent, 113 r.p.m.

All subjects started with the standard at 60 r.p.m.

7.2 *Experiment III and IV*

7.2.1 *Procedure*

Fourteen subjects (7 male, 7 female, age 20—24 years) participated in the experiments. (1 male and 3 females had previously taken part in Exp. I and II.) The velocities used were 20, 36, 60, 90, 113

Table 7.1 a. Experiment III

Individual scale values from the method of magnitude estimation. Silent velocity. Standard, silent 60 r.p.m. = 10.
(Notations after subject number, m = male, f = female.)

Subject No.	20	36	60	90	113	153	r.p.m.
1 f	2.50	5.38	10.00	19.63	26.50	35.00	
2 f	2.13	5.13	10.50	24.50	39.00	47.50	
3 f	3.75	7.50	10.25	14.25	20.00	25.00	
4 f	1.88	5.75	10.25	17.75	20.00	26.25	
5 f	2.50	5.25	9.25	16.25	31.25	47.50	
6 f	4.75	6.00	10.00	16.25	26.25	43.75	
7 f	4.50	5.00	10.00	15.00	18.00	23.75	
8 m	3.50	5.75	10.13	16.13	19.38	27.00	
9 m	3.25	7.13	10.00	12.88	14.38	17.38	
10 m	4.50	7.00	10.00	15.00	19.75	27.75	
11 m	2.33	4.33	12.50	35.00	62.50	95.00	
12 m	3.25	5.75	9.50	18.00	24.25	29.00	
13 m	4.75	7.25	12.25	17.50	22.50	27.25	
14 m	4.75	7.75	7.75	14.50	23.50	27.75	

Table 7.1 b. Experiment III

Individual scale values from the method of magnitude estimation. Loaded velocity, intermittent frequency 12 per second. Standard, silent 60 r.p.m. = 10.
(Notations after subject number, m = male, f = female.)

Subject No.	20	36	60	90	113	153	r.p.m.
1 f	2.00	6.25	10.38	22.00	28.25	38.63	
2 f	2.08	5.63	10.00	26.00	35.00	44.50	
3 f	3.00	7.50	10.75	15.00	19.75	25.00	
4 f	1.75	6.00	10.00	15.50	19.25	23.00	
5 f	5.00	6.75	11.75	17.50	32.50	62.50	
6 f	5.00	7.75	13.25	22.50	33.75	45.00	
7 f	4.00	8.50	10.00	14.75	18.00	23.00	
8 m	3.50	5.75	9.63	15.25	19.50	24.75	
9 m	3.88	7.38	10.00	12.50	15.25	17.88	
10 m	3.25	6.50	12.00	16.75	23.25	27.75	
11 m	2.83	5.00	12.50	35.00	67.50	95.00	
12 m	2.75	6.25	11.00	18.00	24.50	27.75	
13 m	4.50	7.25	13.25	18.75	22.50	27.50	
14 m	5.00	7.50	10.75	15.50	19.00	25.75	

Table 7.2. Experiment III

Standard, silent 60 r.p.m. = 10. Intermittent frequency 12 per second. Difference between loaded and silent scale value for each subject. $\overline{\text{Diff.}}_f$, $\overline{\text{Diff.}}_m$, $\overline{\text{Diff.}}$ = mean difference computed over 7 female, 7 male and 14 subjects respectively. $\overline{\text{Diff.}}_f\%$ etc. are those means given in percent of respective group mean silent scale value.

Subject No.	20	36	60	90	113	153 r.p.m.
1 f	—0.50	0.87	0.38	2.37	1.75	3.63
2 f	—0.04	0.50	—0.50	1.50	—4.00	—3.00
3 f	0.25	0.00	0.50	0.75	—0.25	0.00
4 f	—0.13	0.25	—0.25	—2.25	—0.75	—3.25
5 f	2.50	1.50	2.50	1.25	1.25	15.00
6 f	0.25	1.75	3.25	6.25	7.50	1.25
7 f	—0.50	3.50	0.00	—0.25	0.00	—0.75
8 m	0.00	0.00	—0.50	—0.88	0.12	—2.25
9 m	0.63	0.25	0.00	—0.38	0.87	0.50
10 m	—1.25	—0.50	2.00	1.75	3.50	0.00
11 m	0.50	0.67	0.00	0.00	5.00	0.00
12 m	—0.50	0.50	1.50	0.00	0.25	—1.25
13 m	—0.25	0.00	1.00	1.25	0.00	0.25
14 m	0.25	—0.25	3.00	1.00	—4.50	2.00
$\overline{\text{Diff.}}_f$	0.26	1.20	0.84	1.37	0.78	1.84
$\overline{\text{Diff.}}_m$	—0.09	0.10	1.00	0.39	0.75	0.07
$\overline{\text{Diff.}}$	0.09	0.64	0.92	0.88	0.77	0.88
$\overline{\text{Diff.}}_f\%$	7.51	19.78	8.20	7.59	2.97	5.15
$\overline{\text{Diff.}}_m\%$	—2.60	1.65	9.76	2.16	2.86	0.20
$\overline{\text{Diff.}}\%$	2.60	10.54	8.98	4.88	2.94	2.46

and 153 r.p.m., (the same as in Exp. I and II). Experiment III and IV were run at different sessions in that order. The external conditions are described in Chapter 7, Exp. I and II.

7.2.2 *Results*

For each individual the arithmetic mean of four estimates on each velocity were computed. The individual scales for silent and loaded velocity are given in Table 7.1 for Experiment II and

Table 7.3. a and b. Experiment IV

Individual scale values from the method of magnitude estimation. Standard, silent 113 r.p.m. = 10 Intermittent frequency 12 per second. (Notations after subject number, m = male, f = female.)
a. Silent velocity. b. Loaded velocity.

a.

Subject No.	20	36	60	90	113	153	r.p.m.
1 f	1.50	2.50	4.88	8.13	10.00	16.75	
2 f	1.38	3.00	3.25	7.25	10.75	23.00	
3 f	1.75	3.75	6.50	9.00	12.00	15.75	
4 f	2.00	3.25	5.00	8.00	10.00	14.50	
5 f	1.00	2.75	3.50	6.75	9.75	16.75	
6 f	3.00	3.50	5.75	5.50	10.00	26.25	
7 f	2.75	4.00	5.00	8.75	10.50	17.00	
8 m	2.13	3.25	5.38	7.75	10.38	13.63	
9 m	2.13	4.25	6.50	8.13	10.00	14.50	
10 m	1.81	3.25	5.50	7.50	9.75	13.75	
11 m	1.63	2.75	4.50	7.25	12.50	37.50	
12 m	1.75	2.75	5.00	8.50	10.25	15.75	
13 m	4.75	6.75	8.25	9.50	12.25	17.50	
14 m	4.50	8.75	6.75	7.00	10.00	19.00	

b.

Subject No.	20	36	60	90	113	153	r.p.m.
1 f	1.38	3.20	5.25	7.88	10.50	18.25	
2 f	1.38	2.13	4.25	7.25	10.00	24.25	
3 f	2.50	4.50	6.50	8.50	12.25	17.00	
4 f	1.88	3.25	5.00	7.25	10.00	14.00	
5 f	3.00	3.00	4.60	6.75	10.75	17.50	
6 f	3.00	4.75	6.00	8.00	12.50	25.00	
7 f	2.38	5.25	5.75	9.00	10.00	16.00	
8 m	1.94	3.38	5.38	7.88	10.25	13.63	
9 m	1.88	4.75	6.50	8.25	10.25	16.00	
10 m	1.13	2.75	4.75	8.00	11.00	16.00	
11 m	1.88	2.75	4.50	7.75	20.00	50.00	
12 m	1.00	2.25	4.75	8.50	11.25	16.25	
13 m	4.00	6.00	8.00	10.50	12.75	16.50	
14 m	6.00	7.00	6.00	8.75	8.50	22.00	

Table 7.4. Experiment IV

Standard, silent 113 rp.m. = 10. Intermittent frequency 12 per second. Difference between loaded and silent scale value for each subject. $\overline{\text{Diff.}}_f$, $\overline{\text{Diff.}}_m$, $\overline{\text{Diff.}}$ = mean difference computed over 7 female, 7 male and 14 subjects respectively. $\overline{\text{Diff.}}_f\%$ etc. are those means given in percent of the group mean silent scale value.

Subject No.	20	36	60	90	113	153 r.p.m.
1 f	—0.12	0.70	0.37	—0.25	0.50	1.50
2 f	0.00	—0.87	1.00	0.00	—0.75	1.25
3 f	0.75	0.75	0.00	—0.50	0.25	1.25
4 f	—0.12	0.00	0.00	—0.75	0.00	—0.50
5 f	2.00	0.25	1.10	0.00	1.00	0.75
6 f	0.00	1.25	0.25	2.50	2.50	—1.25
7 f	—0.37	1.25	0.75	0.25	—0.50	—1.00
8 m	—0.19	—0.13	0.00	0.13	—0.13	0.00
9 m	—0.25	0.50	0.00	0.12	0.25	1.50
10 m	—0.68	—0.50	—0.75	0.50	1.25	2.25
11 m	0.25	0.00	0.00	0.50	7.50	12.50
12 m	—0.75	—0.50	—0.25	0.00	1.00	0.50
13 m	—0.75	—0.75	—0.25	1.00	0.50	—1.00
14 m	1.50	—1.75	—0.75	1.75	—1.50	3.00
$\overline{\text{Diff.}}_f$	0.30	0.48	0.50	0.18	0.28	0.28
$\overline{\text{Diff.}}_m$	—0.12	—0.45	—0.28	0.57	1.27	2.68
$\overline{\text{Diff.}}$	0.09	0.02	0.10	0.38	0.78	1.48
$\overline{\text{Diff.}}_f\%$	13.10	12.33	9.24	2.31	2.65	1.50
$\overline{\text{Diff.}}_m\%$	—5.24	—11.57	—5.18	7.32	12.00	14.34
$\overline{\text{Diff.}}\%$	3.93	0.51	1.85	4.88	7.37	7.92

Table 7.3 for Experiment IV. Diagrams 7.1 and 7.3 show plots between silent and loaded scale values. Both plots deviate slightly from the zero-effect 45° slope.

In Tables 7.2 and 7.4 are given the differences between loaded and silent scale values. These differences are illustrated in Diagrams 7.2 and 7.4. In general, the results agree with those found in Exp. I and II. The effect of the intermittent stimulation is small or negative for the lowest velocity used (20 r.p.m.) and positive

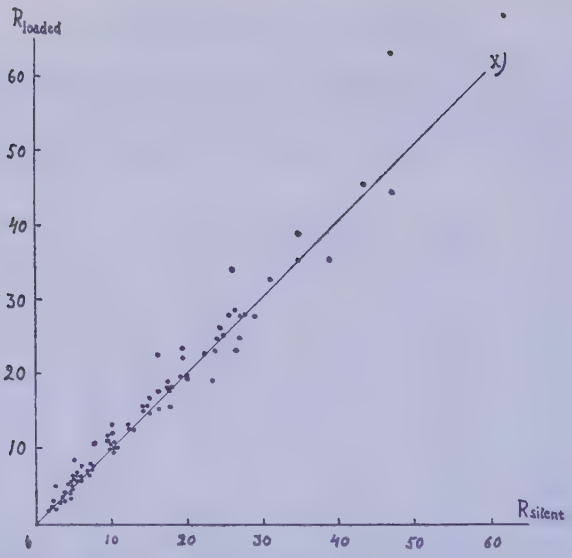


Diagram 7.1 Experiment III. Plot of silent scale values against loaded scale values. Magnitude estimation. Standard, silent 60 r.p.m. = 10. Number of subjects = 14.
*) One pair of values for Subject 11 (95/95) is not in the diagram.

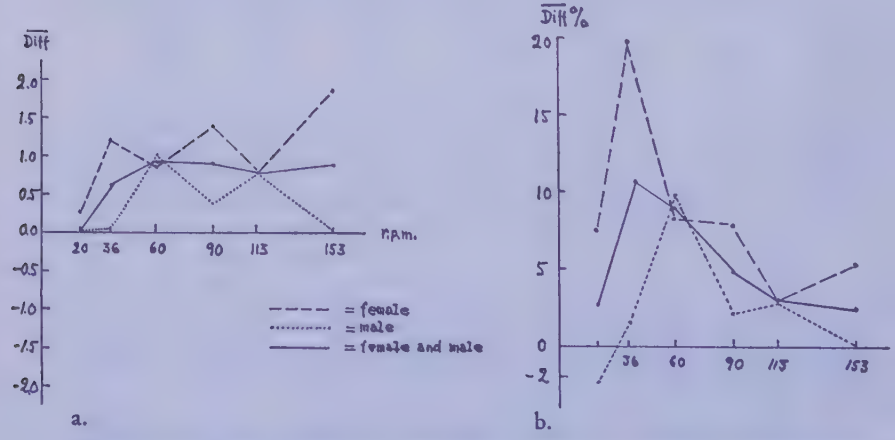


Diagram 7.2 Experiment III. Standard, silent 60 r.p.m. = 10, intermittent frequency 12 per second.
a. Compared velocities plotted against mean difference between loaded and silent velocity, (Diff.). b. Diff. given in percent of mean silent scale value (Diff %).

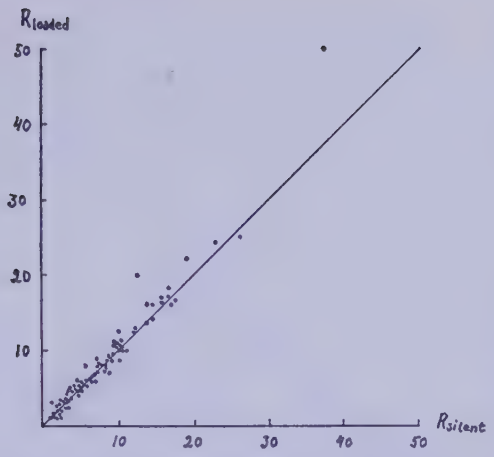
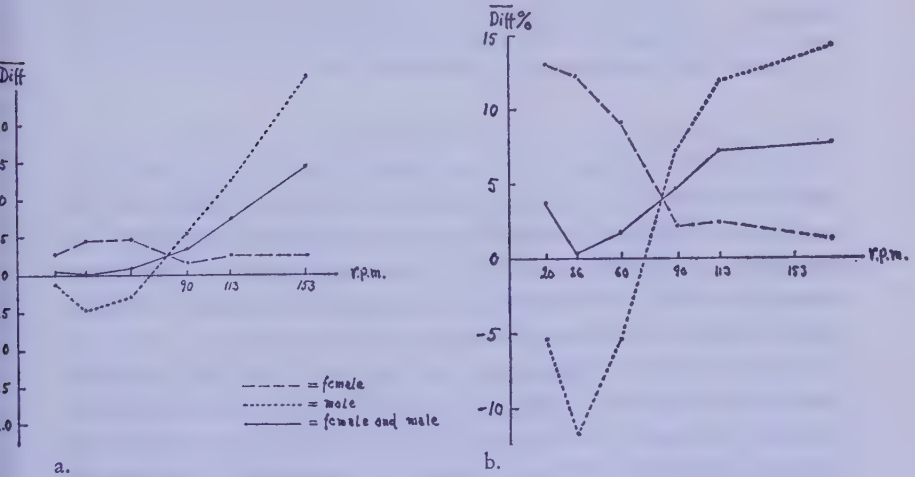


Diagram 7.3 Experiment IV. Plot of silent scale values against loaded scale values. Magnitude estimation. Standard, silent 113 r.p.m. = 10. Number of subjects = 14. Intermittent frequency 12 per second.



a. b.

Diagram 7.4 Experiment IV. Standard, silent 113 r.p.m. = 10. Intermittent frequency 12 per second.
a. Compared velocities plotted against mean difference between loaded and silent scale value, (Diff.). b. Diff. given in percent of mean silent scale value, (Diff %).

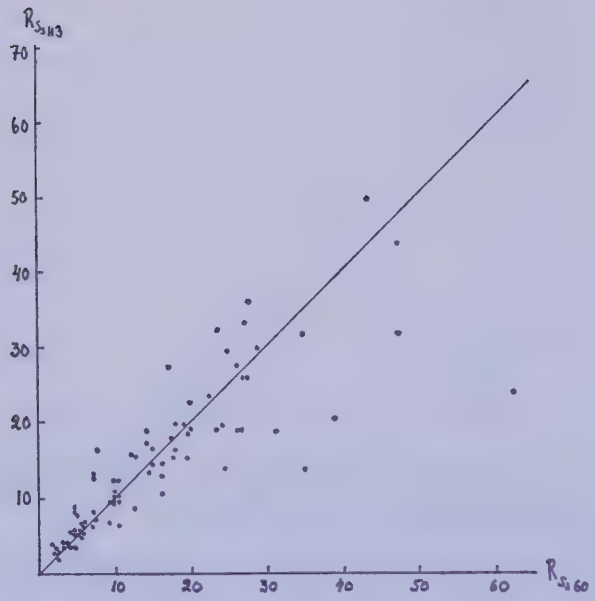


Diagram 7.5 Plot of individual scale values for silent velocity. Experiment III (Standard 60 r.p.m. = 10) against Experiment IV (Standard 113 r.p.m. = 10). Data from Experiment IV linearly transformed by multiplication of 1.89 (= ratio between the means of the scale values for 60 r.p.m.).

(between 5 and 10 % of the corresponding silent scale value) for the higher velocities. Our working hypothesis is thus supported by the results. Intermittent auditive stimulation exerts a small but systematic effect on the experience of velocity when this velocity is estimated by the method of magnitude estimation.

In Exp. I and II a negative effect was also found in the case of the highest velocity. In Exp. III and IV the effect at the comparable position is positive, but the effect curves show a levelling or small decrease at these positions. Further, the effect may be affected by the position of the standard. The group difference-curves in both Exp. III and IV (Diagrams 7.2 and 7.4) reach their highest level around the position of the standard. The group curves must, however, be treated with caution. As seen from Tables 7.2

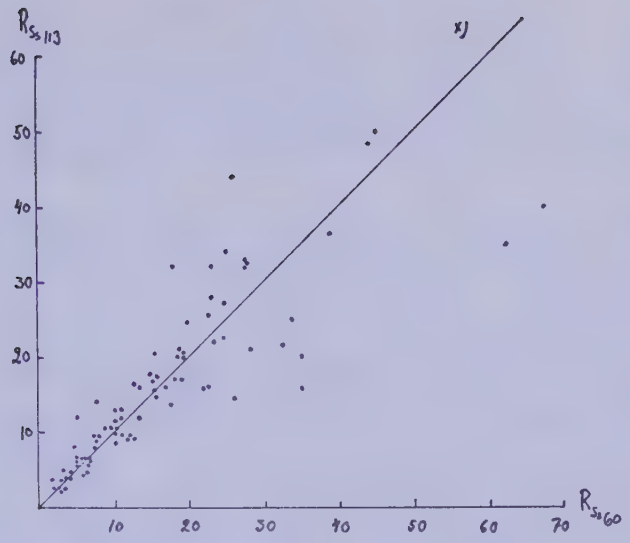


Diagram 7.6 Plot of individual scale values for loaded velocity. Experiment III (Standard 60 r.p.m. = 10) against Experiment IV (Standard 113 r.p.m. = 10). Data from Experiment IV linearly transformed by multiplication of 2.01 (ratio between the means of the values for 60 r.p.m.).
*) One pair of values for Subject 11 (95/50) is not in the diagram.

and 7.4 there is a differential individual susceptibility to the intermittent stimulation. Female and male subjects show different typical patterns, the males usually showing a negative effect at low velocities. It is, however, impossible at this stage do draw any conclusions as to whether this difference is due to a different susceptibility to the intermittent stimulation as such or if it is related to e.g. an anchoring mechanism relative to the standard used.

In Diagram 7.5 is shown the plot between the silent scales from Exp. III and IV and in Diagram 7.6 the corresponding plot is given for the loaded scales. Although the variation between experiments is naturally greater than the one within experiment variation the plots do not show any systematic deviation from the 45° slope.

Diagram 7.7 shows plots between the first and fourth estimation for the silent and the loaded scales. The plots indicate that the

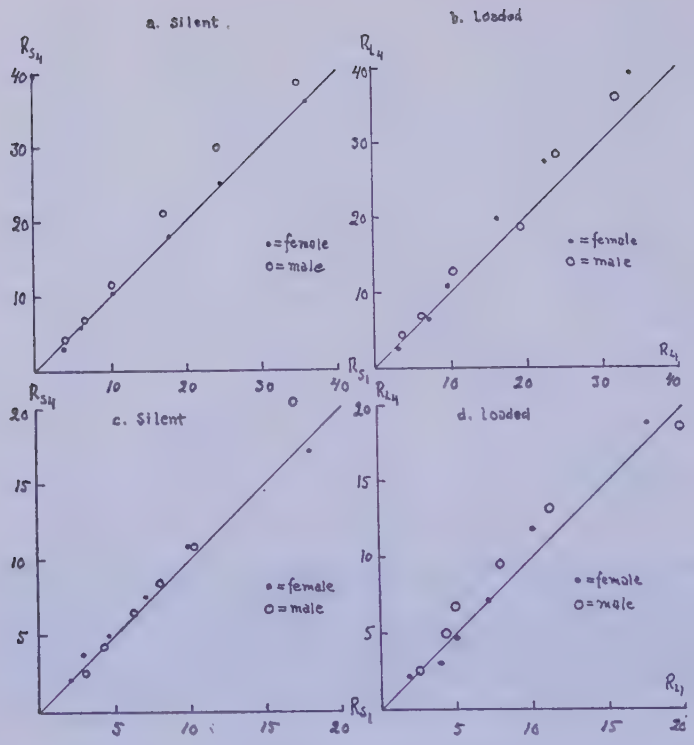


Diagram 7.7 Plot between first (R_{S1}, R_{11}) and fourth (R_{S4}, R_{14}) estimate for silent (a and c) and loaded (b and d) velocity in Experiment III (a, b) and Experiment IV (c, d).

loaded scale values are subject to a greater change over trials 1 to 4 than the silent scale values. In Experiment III the change in loaded values for the female group is 3 times as great as the change in silent values. For the male group the loaded change is only slightly greater. In Experiment IV this relation is the same for both groups, being about 1:2.5. It should be remembered that the same observation was made in Exp. I and II.

The linear 45° slope tendency in Diagrams 7.5, 7.6, 7.7 a and c is also a rough indication that the method of magnitude estimation in this case provides data that are internally consistent.

Table 7.5 a and b. Experiment V

Individual scale values from the method of magnitude estimation. Standard, silent 60 r.p.m. = 10. Intermittent frequency 5 per second.
(Notations after subject number, m = male, f = female.) a. Silent velocity. b. Loaded velocity.

a.

Subject No.	20	36	60	90	113	153 r.p.m.
1 f	3.25	6.50	9.50	20.00	26.25	38.75
2 f	4.25	6.75	9.25	15.25	17.73	21.00
3 f	4.38	7.50	10.63	16.25	18.75	22.50
4 f	4.75	6.25	10.25	14.50	15.75	20.25
5 f	5.75	8.00	10.00	14.50	17.50	22.25
6 m	3.00	6.25	9.25	13.25	21.00	23.00
7 m	4.25	7.25	10.00	15.00	17.75	24.00
8 m	2.75	5.38	8.50	15.50	24.38	36.63
9 m	2.55	5.85	9.63	16.25	22.00	29.50
10 m	2.63	6.50	9.50	15.00	19.50	24.75

b.

Subject No.	20	36	60	90	113	153 r.p.m.
1 f	2.00	5.75	10.00	22.50	35.00	46.25
2 f	4.25	6.75	10.25	15.50	20.00	24.25
3 f	5.00	8.13	11.88	19.38	20.00	22.50
4 f	4.25	6.50	12.00	19.00	23.75	23.50
5 f	5.75	9.75	10.25	15.00	18.50	25.50
6 m	2.00	6.00	9.50	17.00	20.75	26.25
7 m	5.00	7.75	10.00	13.25	16.50	22.50
8 m	2.88	5.00	10.88	15.38	22.38	37.00
9 m	2.55	6.08	9.70	17.10	23.00	30.00
10 m	2.50	5.75	11.00	15.75	20.25	28.75

7.3 *Experiment V and VI*

7.3.1 *Procedure*

Ten subjects (5 female, 5 male, age 20–24 years) participated in the experiments. (One male subject had previously taken part in Exp. I and II.) The velocities used were the same as in Exp. I to

Table 7.6. Experiment V

Standard, silent 60 r.p.m. = 10. Intermittent frequency 5 per second. Difference between loaded and silent scale value for each subject. $\overline{\text{Diff.}}_f$, $\overline{\text{Diff.}}_m$, $\overline{\text{Diff.}}$ = mean difference computed over 5 female, 5 male and 10 subjects respectively. $\overline{\text{Diff.}}_f\%$ etc. are those means given in percent of the group mean silent scale value.

Subject No.	20	36	60	90	113	153 r.p.m.
1 f	—1.25	—0.75	0.50	2.50	8.75	7.50
2 f	0.00	0.00	1.00	0.25	2.27	3.25
3 f	0.62	0.63	1.25	3.13	1.25	0.00
4 f	—0.25	0.25	1.75	4.50	8.00	3.25
5 f	0.00	1.75	0.25	0.50	1.00	3.25
6 m	—1.00	—0.25	0.25	3.75	—0.25	3.25
7 m	0.75	0.50	0.00	—1.75	—1.25	—1.50
8 m	0.13	—0.38	2.38	—0.12	—2.00	—0.37
9 m	—0.20	0.23	0.07	0.85	1.00	0.50
10 m	—0.13	—0.75	1.50	0.75	0.75	4.00
$\overline{\text{Diff.}}_f$	—0.18	0.38	0.95	2.18	4.25	3.45
$\overline{\text{Diff.}}_m$	—0.09	—0.22	0.84	0.70	—0.35	1.18
$\overline{\text{Diff.}}$	—0.13	0.07	0.89	1.44	1.95	2.31
$\overline{\text{Diff.}}_f\%$	—4.79	5.74	9.84	14.02	21.19	13.13
$\overline{\text{Diff.}}_m\%$	—2.39	—3.32	8.70	4.50	—1.74	4.49
$\overline{\text{Diff.}}$	—3.46	1.06	9.22	9.26	9.72	8.80

IV, (see tables). The only difference from Exp. III and IV was that the intermittent frequency was changed from 12 per second to 5 per second in Exp. V and VI. In Exp. V the silent velocity of 60 r.p.m. was standard and called 10. In Exp. VI the standard was 113 r.p.m. and also called 10. Exp. V and VI were done at different sessions in that order. The external conditions are described in Section 7.1 and Appendix 1.

7.3.2 *Results*

The arithmetic mean of four estimates for each velocity and individual was computed.

Table 7.7 a and b. Experiment VI

Individual scale values from the method of magnitude estimation. Standard, silent 113 r.p.m. = 10. Intermittent frequency 5 per second.
(Notations after subject number, m = male, f = female.) a. Silent velocity. b. Loaded velocity.

a.

Subject No.	20	36	60	90	113	153 r.p.m.
1 f	1.00	2.75	5.00	8.00	10.00	23.75
2 f	2.00	3.00	4.75	7.50	9.75	15.00
3 f	5.00	6.88	8.13	9.38	10.00	13.13
4 f	3.75	5.50	5.50	9.00	12.25	17.00
5 f	3.50	5.00	6.50	8.50	10.00	17.50
6 m	2.13	3.65	5.50	8.00	10.00	17.25
7 m	2.38	3.00	6.25	8.25	10.00	16.25
8 m	2.13	3.63	5.75	8.50	10.00	15.38
9 m	2.15	4.30	6.75	9.00	10.00	17.75
10 m	2.00	3.50	5.13	7.13	10.00	16.75

b.

Subject No.	20	36	60	90	113	153 r.p.m.
1 f	1.00	3.50	5.75	8.00	10.00	25.00
2 f	2.25	3.75	5.50	8.25	10.25	15.50
3 f	4.38	5.63	7.50	9.38	10.00	15.00
4 f	3.75	5.00	6.50	10.25	13.75	16.00
5 f	3.75	5.75	7.75	9.50	11.25	21.00
6 m	2.00	3.65	6.50	9.00	11.50	18.00
7 m	2.13	3.13	5.25	8.25	9.75	14.25
8 m	1.63	2.88	5.38	8.75	10.38	15.75
9 m	1.85	3.33	5.93	8.78	10.75	18.75
10 m	2.00	4.25	5.00	7.63	10.00	20.00

The individual scales for silent and loaded velocity are given in Table 7.5 for Exp. V and Table 7.7 for Exp. VI. Diagrams 7.8 and 7.10 show the plots between silent and loaded scale values. Both plots deviate slightly from the zero-effect 45° slope.

Table 7.8. Experiment VI

Standard silent 113 r.p.m. = 10. Intermittent frequency 5 per second. Difference between loaded and silent scale value for each subject. $\overline{\text{Diff.}}_f$, $\overline{\text{Diff.}}_m$, $\overline{\text{Diff.}}$ = mean difference computed over 5 female, 5 male and 10 subjects respectively. $\overline{\text{Diff.}}_f\%$ etc. are those means given in percent of the group mean silent scale value.

Subject No.	20	36	60	90	113	153 r.p.m.
1 f	0.00	0.75	0.75	0.00	0.00	1.25
2 f	0.25	0.75	0.75	0.75	0.25	0.50
3 f	—0.62	—1.25	—0.63	0.00	0.00	1.87
4 f	0.00	—0.50	1.00	1.25	1.50	—1.00
5 f	0.25	0.75	1.25	1.00	1.25	3.50
6 m	—0.13	0.00	1.00	1.00	1.50	0.75
7 m	—0.25	0.13	—1.00	0.00	—0.25	—2.00
8 m	—0.50	—0.75	—0.37	0.25	0.38	0.37
9 m	—0.15	—0.97	—0.82	—0.22	0.75	1.00
10 m	0.00	0.75	—0.13	0.50	0.00	3.25
$\overline{\text{Diff.}}_f$	—0.02	0.10	0.62	0.60	0.60	1.22
$\overline{\text{Diff.}}_m$	—0.21	—0.17	—0.26	0.31	0.48	0.67
$\overline{\text{Diff.}}$	—0.12	—0.03	0.18	0.45	0.54	0.95
$\overline{\text{Diff.}}_f\%$	—0.77	2.43	10.45	7.20	5.88	7.18
$\overline{\text{Diff.}}_m\%$	—8.08	—4.13	—4.38	3.72	4.70	3.94
$\overline{\text{Diff.}}\%$	—4.62	0.73	3.03	5.40	5.29	5.59

In Tables 7.6 and 7.8 are given the differences between loaded and silent individual scale values. The mean differences from those tables are illustrated in Diagrams 7.9 and 7.11.

The results agree with those found earlier. Thus, our working hypothesis is again supported. As in Exp. III and IV the effect at the highest velocity studied is positive for both female and male groups, as opposed to the finding in Exp. I and II. In agreement with the previous experiments the effect at the lowest velocity studied is near zero or negative.

When Exp. III and IV are compared to Exp. V and VI, no differential effect of the intermittent frequencies of 12 per second

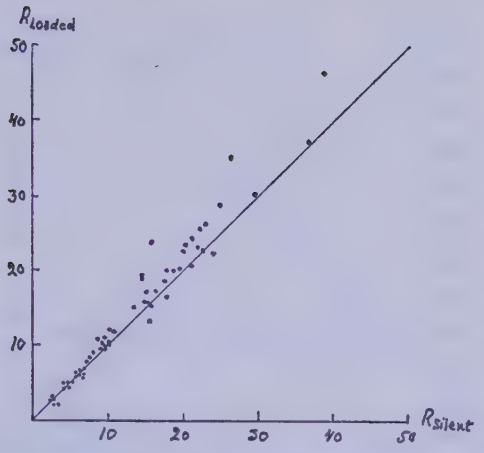


Diagram 7.8 Experiment V. Plot of silent scale values against loaded scale values. Standard, silent 60 r.p.m. = 10. Number of subjects = 10. Intermittent frequency 5 per second.

and 5 per second could be detected. This finding is also in agreement with the results from Exp. I and II. The pattern and the direction of the effect over the velocity range studied is the same for both intermittent frequencies. This comparison should, however, be interpreted with caution as different subjects participated in Exp. III, IV and V, VI.

From Diagrams 7.9 and 7.11 is seen that the curve for the female subjects in general lies above the male curve. The same tendency was seen in Exp. III while in Exp. IV the relation between the groups was more complex. The shift of standard from 60 r.p.m. to 113 does appear to exert some influence on the effect under study. In both experiments the peak value of the effect (group curves) lies near the standard position.

The same differential individual susceptibility to the intermittent stimulation as observed in Exp. III and IV is seen here again. The difference between female and male subjects mentioned above may also be described by saying that male subjects more often start with negative effects.

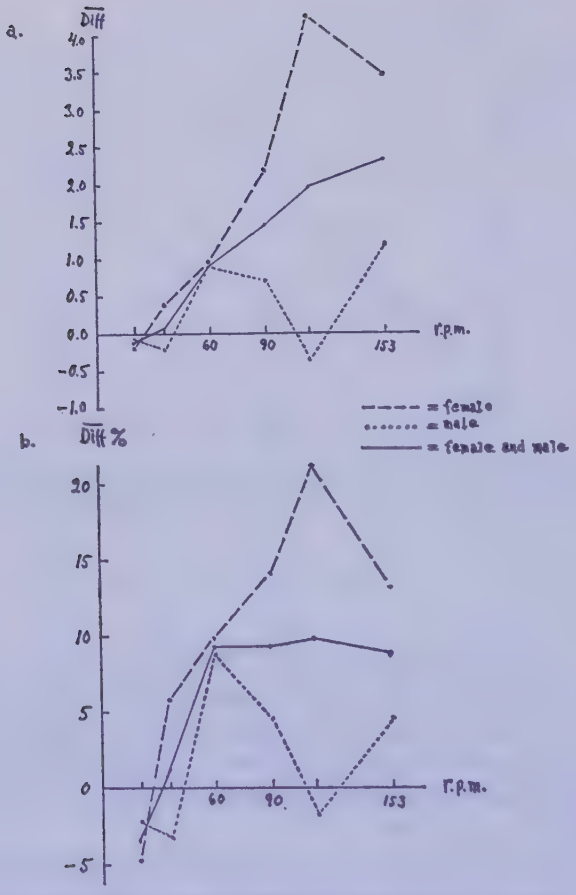


Diagram 7.9 Experiment V. Standard, silent 60 r.p.m. = 10. Intermittent frequency 5 per second.
a. Compared velocities plotted against mean difference between loaded and silent scale value, ($\overline{\text{Diff.}}$). b. $\overline{\text{Diff.}}$ given in percent of mean silent scale value, ($\overline{\text{Diff}}$ %).

The plot between silent scale values from Exp. V and VI is shown in Diagram 7.12 and the corresponding plot of loaded values from the same experiments is shown in Diagram 7.13. No marked deviation from the 45° slope is apparent. The variation is great and similar to that earlier found in Exp. III and IV.

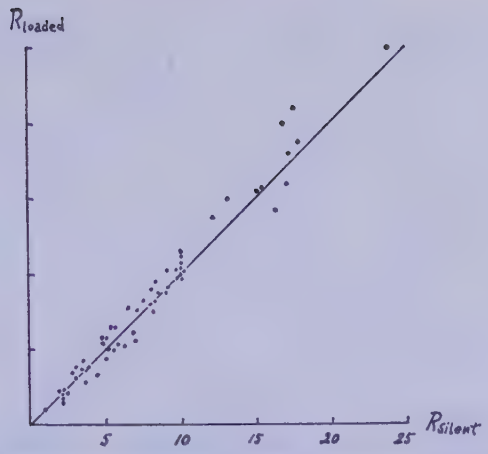
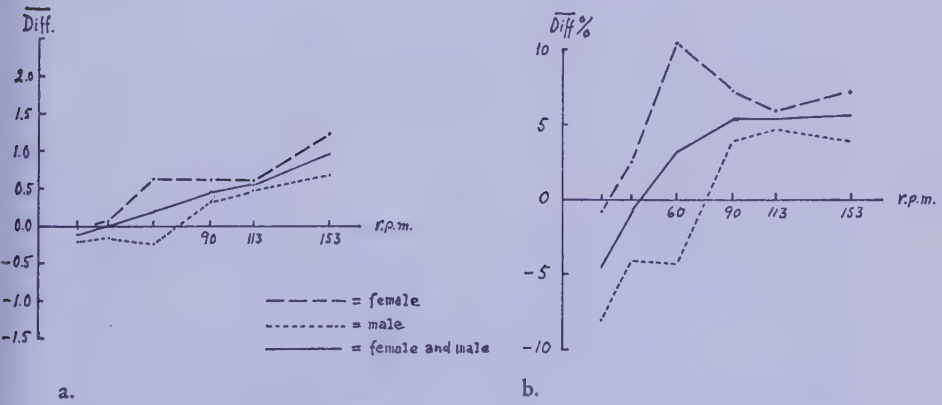


Diagram 7.10 Experiment VI. Plot of silent scale values against loaded scale values. Magnitude estimation. Standard, silent 113 r.p.m. = 10. Number of subjects = 10. Intermittent frequency 5 per second.



a. b.

Diagram 7.11 Experiment VI. Standard, silent 113 r.p.m. = 10. Intermittent frequency 5 per second.
a. Compared velocities plotted against mean difference between loaded and silent scale value, (Diff.). b. Diff. given in percent of mean silent scale value, (Diff %).

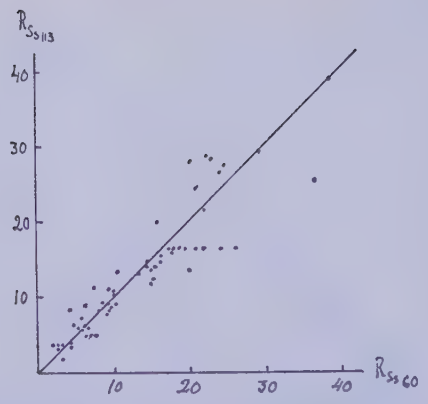


Diagram 7.12. Plot of individual scale values for silent velocity. Experiment V (Standard, silent 60 r.p.m. = 10) against Experiment VI (Standard, silent 113 r.p.m. = 10). Data from Experiment VI lienarly transformed by multiplication of 1.63 (= ratio between the means of the scale values for 60 r.p.m.).

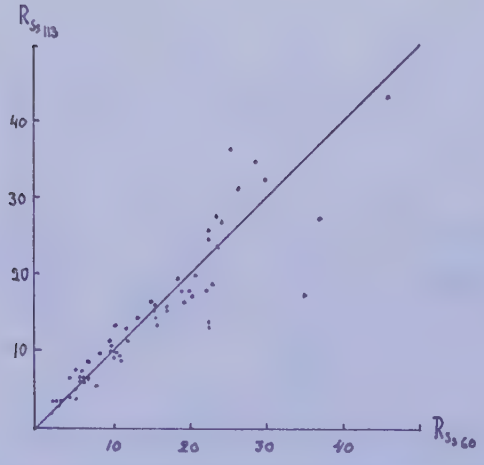


Diagram 7.13 Plot of individual scale values for loaded velocity. Experiment V (Standard, silent 60 r.p.m. = 10) against Experiment VI (Standard, silent 113 r.p.m. = 10). Data from Experiment VI linearly transformed by multiplication of 1.73 (= ratio between the means of the scale values for 60 r.p.m.).

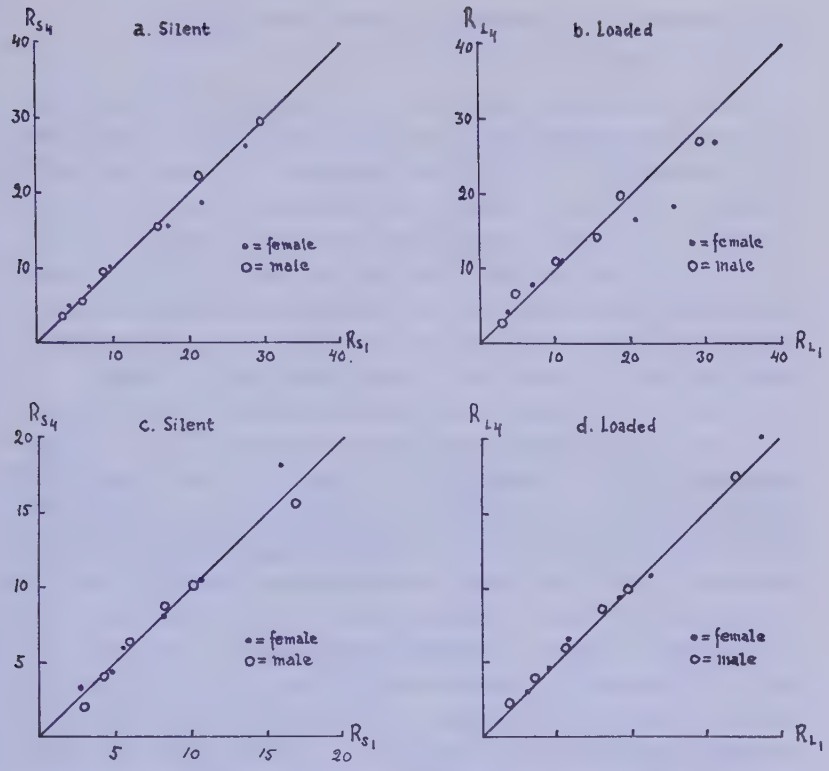


Diagram 7.14 Plot between first (R_{S1}, R_{11}) and fourth (R_{S4}, R_{14}) estimate for silent (a and c) and loaded (b and d) velocity in Experiment V (a, b) and Experiment VI (c, d).

Diagram 7.14 show plots between the first and fourth estimations for silent and loaded scale values. In Exp. V the change for loaded scale values is slightly greater than the change in silent values. In Exp. VI the change is small and about the same for both loaded and silent scales. The change observed in these two experiments is smaller than, and goes in the opposite direction to that earlier found in Exp. I to IV.

The linear 45° slope tendency in Diagrams 7.12, 7.13 and 7.14 a and c is also a rough estimate of the consistency of the data from the method of magnitude estimation.

7.4 *Discussion and summary of results from Experiments III to VI*

The four experiments reported in this chapter used a modified method of magnitude estimation. The same subjects were tested with the standard at two different positions. One group was tested with the auditive intermittent stimulation of 12 per second (Exp. III and IV), the other group with 5 per second (Exp. V and VI). Each velocity was presented together with the standard in a predetermined time-order sequence. The difference between Exp. I and II and Exp. III–VI is thus confined to the measurement technique and the restriction in presentation time and order.

My working hypothesis, that a loaded velocity should be over-estimated (as compared to a silent velocity) and that this over-estimation should be measurable by magnitude estimation, is in general supported. In all four experiments an over-estimation is observed at five out of six measured points. The relative size and direction of the effect agrees with that found in Exp. I and II. A difference in result is that in Exp. I and II the lowest and highest velocities were under-estimated while in Exp. III to VI only the lowest was under-estimated. In Exp. III to VI a levelling or small decrease of the effect at the higher velocities was found however. Further empirical evidence is needed before this point can be adequately resolved. A possible analysis giving some further information on this point is to plot the scales from magnitude estimation experiments against the ratio matrix row from experiments I and II corresponding to the stimulus used as standard stimulus in experiments III to VI. In order to be comparable the ratio matrix row has to be inverted and divided by 10. Provided the intermittent frequency has the same effect in both types of experiment and if both magnitude estimation and ratio estimation yield consistent data, these plots should be linear with a 45° slope.

The plots are given in Diagrams 7.15, 7.16, 7.17 and 7.18. The plots show that the two methods agree fairly well up to the value of the standard where a break from 45° slope occurs. No ready explanation of this phenomenon is available. A tentative explana-

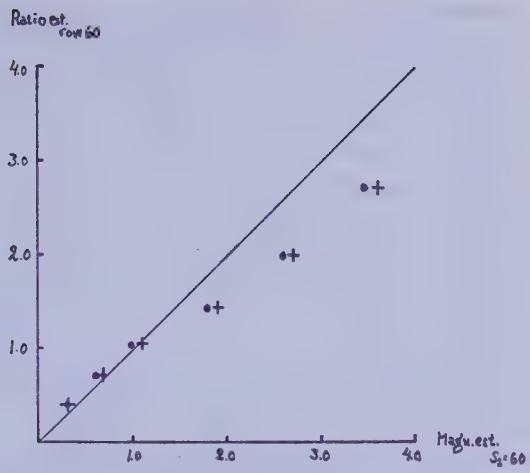


Diagram 7.15 Scales from Experiment III, Ss,60 = 10, intermittent frequency 12 per second, plotted against $1/_{\text{row } 60}$: 10 from Experiment I, ratio estimation.
. silent magnitude estimation scale.
+ loaded magnitude estimation scale.

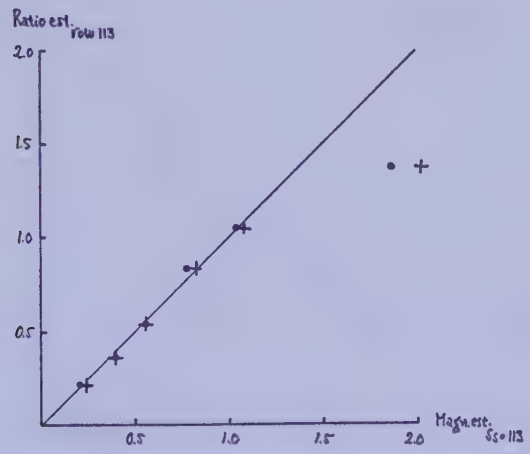


Diagram 7.16 Scales from Experiment IV, Ss, 113 = 10, intermittent frequency 12 per second plotted against $1/_{\text{row } 113}$: 10 from Experiment I, ratio estimation.
. silent magnitude estimation scale.
+ loaded magnitude estimation scale.

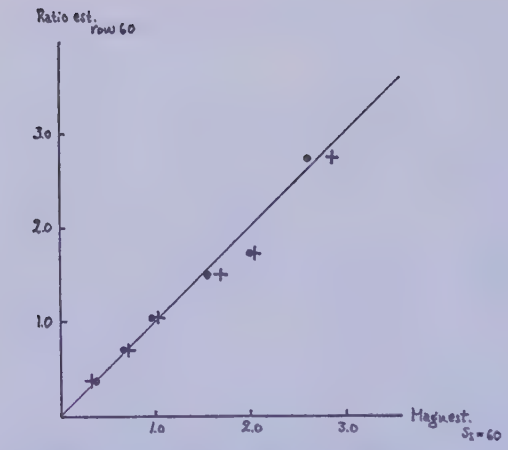


Diagram 7.17 Scales from Experiment V, Ss, 60 = 10, intermittent frequency 5 per second plotted against $1/_{\text{row } 60}$: 10 from Experiment II, ratio estimation.

. silent magnitude estimation scale.

+ loaded magnitude estimation scale.

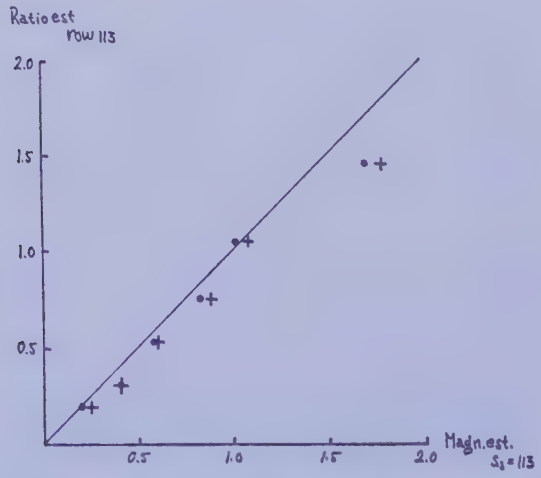


Diagram 7.18 Scales from Experiment VI, Ss, 113 = 10, intermittent frequency 5 per second plotted against $1/_{\text{row } 113}$: 10 from Experiment II, ratio estimation.

. silent magnitude estimation scale.

+ loaded magnitude estimation scale.

tion may be given however. It has been shown by Eisler (1960), and Goude (1962) that the method of ratio estimation gives rise to inconsistent matrices. Eisler's data indicate that ratios for small S are under-estimated relative to the standard stimulus while ratios for high S are apt to be over-estimated. If it is further assumed that the method of magnitude estimation gives consistent estimates, a plot between magnitude scales and corresponding inverted rows from ratio matrices should lie above the 45° line for small S and below the line for high S. This description fits the present plots fairly well.

For lack of further empirical evidence this point is not carried further here. It will however be taken up in another context in Chapter 9.

At the lowest velocity studied, the male groups showed a negative effect. It is, however, unclear whether this difference between sexes is real or if it should be seen as an indication of a general variation over subjects in the evaluation of, or reaction to, the intermittent stimulation, irrespective of sex. A closer look at individual data makes the latter interpretation seems more plausible as the relative effect seems to change systematically with physical velocity, being small or negative for low intensities, increasing when velocity is increased and eventually levelling out or decreasing with further increase in velocity.

The effect appears to reach its maximum around the position of the standard. This tendency is, however, very slight. No differential effect of the intermittent frequencies of 12 per second and 5 per second was apparent. As different subjects received different intermittent frequencies this result should also be treated with caution. Both the direction and the relative magnitude of the effect agree for the two frequencies tested. According to Johansson and Frankenhauser earlier cited, changes in the flow of the time stream or the flow of mental events should be the crucial factor. This would imply that the different intermittent frequencies ought to yield different results.

In Exp. I and II the effect of intermittent frequency was thought to vary with the number of trials. The same finding was made in Exp. III and IV, while in Exp. V and VI the effect was

smaller and in one case reversed. It may be argued that this change is too small to be of any importance. I have studied it for four reasons. It has been reported before. It occurred in a systematic pattern in four consecutive experiments. The change is different for silent and loaded velocity and the change in the loaded values from trial 1 to trial 4 is of about the same order of magnitude as the total effect observed when arithmetic means are computed over trials. I therefore expect that the effect will show a development over trials so that it is large at the start, diminishes in the middle and reoccurs at the end. This prediction will be further tested and discussed in the following chapters.

No questions are answered unequivocally by these experiments and new problems have turned up. Let me put down the state of affairs so far point for point.

1. Auditive intermittent stimulation affects judgement of subjective velocity.
2. This effect can be measured by ratio scaling and magnitude estimation.
3. It is unclear whether the effect observed is due to changes in the judgemental language of the subjects or to changes in the subjects perception.
4. The influence of response inconsistency on the effects observed is unclear.
5. A differential individual susceptibility to the effect is observed.
6. It is not probable that a sex difference exists.
7. The effect is different in direction and size at different velocities.
8. It is probable that the effect levels off or diminishes at high velocities.
9. It is unclear whether it is affected by the position of the standard in magnitude estimation.
10. It is unclear if it is affected by the type of judgement-scale used (closed at both ends, open-ended).
11. It is unclear whether different intermittent frequencies give different effects.

12. It is probable that the scale values for loaded velocity changes more over trials than silent scale values.
13. The effect is probably highest on the first trial (diminishing over the next two and eventually reappearing on the fourth trial).
14. It is unclear how subjects judge intermittent auditive stimulation and visual velocity. It seems reasonable that the same attribute is judged in both types of stimulation.
15. No simple description can be offered as to how subjects combine the auditive and visual stimulation so that the resulting scale is changed.

Four experiments on generalized ratio scaling of silent and loaded velocity and intermittent auditive frequency

8.1 *Introduction*

The four experiments to be reported in this chapter should be seen in relation to Exp. I and II described in Chapter 6.

Exp. I and II were preliminary experiments, crudely analysed and raising more questions than they answered. Subsumptions supported or suggested by results from Exp. I and II were in short:

1. A tendency to overestimate loaded velocity as compared to silent velocity.
2. The relative strength of this tendency showed a bimodal change over the velocities studied.
3. A very weak indication was found of a decrease of the effect over trials one to four.

Points 1 and 3 were in general supported by the results from Exp. III to VI reported in Chapter 7. Point 2 was not supported. It was tentatively suggested that the bimodal effect curve found in Exp. I and II was due to the method of measurement used, viz. ratio scaling using a scale bound at two ends.

Further problems raised by the results from Exp. I and II concerned a) the internal consistency of the ratio matrices and b) the question of whether subjects experience and judge the same attribute in the intermittent auditive stimulation as in the visual motion presented simultaneously. This second question deals with the problem of dimensionality of ratio matrices.

8.2 *Problems*

The aim of the experiments in this chapter was on the one hand to verify (or nullify) the findings from specifically Exp. I and II, and on the other hand to obtain data for an explorative study of consistency and dimensionality of ratio matrices from the generalized ratio scaling method. In relation to these problems the question of the unit of measurement is discussed.

8.2.1 *Internal consistency and dimensionality*

Testing the internal consistency of ratio matrices from the generalized ratio scaling method, employing nonidentical stimuli as row and column entries, raises special problems. Applying the model $q_{ij} = R_i/R_j$ (where q_{ij} is the stated ratio between stimuli i and j and R_i and R_j are the subjective values of stimuli i and j respectively), one conventional procedure for this test when using ratio matrices with identical stimuli on both axes consists of plotting the empirical ratios against the mean of computed ratios, see e.g. Torgerson (1958). A matrix is considered internally consistent if this plot is linear with a 45° slope. A ratio q_{ij} is estimated by computing

$$q_{ij} = q_{kj}/q_{ki} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$
$$(k = 1, 2, \ldots\ldots\ldots\ldots n)$$

Each empirical ratio in an $(n \times n)$ matrix could thus be estimated in addition by $(n-1)$ computed ratios provided the geometric mean is used within each cell. This procedure could not be applied, however, if the rows and columns contain nonidentical sets of stimuli as in the case when the generalized ratio scaling method is used. Instead the expression

$$q_{ij} = q_{kj} \cdot q_{ih}/q_{kh} \text{ where } \begin{matrix} k \neq i \\ h \neq j \end{matrix} \quad \ldots\ldots\ldots\ldots (2)$$

can be computed. For each empirical ratio (n_1-1) (n_2-1) additional ratios could be computed. (n_1, n_2 = the number of stimuli used as entries for rows and columns respectively.) But, equation

(2) is true only under special conditions. If the absolute subjective magnitudes judged in the equation are written: A_i, B_j, A_k, B_h; (where A:s are stimuli in the column set, B:s stimuli in the row set), equation (2) could be rewritten:

$$\frac{\cos \varnothing_{ai\,bj} \cdot /A_i/}{/B_j/} = \frac{\cos \varnothing_{ak\,bj} \cdot /A_k/}{/B_j/} \cdot \frac{\cos \varnothing_{ai\,bh} \cdot /A_i/}{/B_h/} \cdot \frac{/B_h/}{\cos \varnothing_{ak\,bh} \cdot /A_k/} \quad (3)$$

which reduces to

$$\frac{\cos \varnothing_{ai\,bj} \cdot /A_i/}{/B_j/} = \frac{\cos \varnothing_{ak\,bj} \cdot \cos \varnothing_{ai\,bh} / A_i/}{\cos \varnothing_{ak\,bh} \cdot /B_j/} \quad \ldots\ldots (4)$$

Equation (4) is obviously not an identity unless the angle $\varnothing$ is constant or 0. Thus, if the means of the computed ratios (q_{comp}) from equation (2) are plotted against the empirical ratios (q_{emp}) and the plot is linear with 45° slope, this is a test of internal consistency if it could be shown independently that the same ratio matrix is uni-dimensional.

One such test is to do a factor-analysis of the matrix showing that the first latent root of the matrix adequately describes the variation of the matrix. Tucker (1958), Rao (1958) and Weitzman (1963) describe a factor analytic method by which the test described above could be performed. Dr. Lennart Sjöberg at the University of Stockholm has made a computer program for the IBM 7090 available for the computational work involved. A description of the factor analytic program used may be found in Lilly, Sjöberg, and Frederiksen (1965). The exploratory study of internal consistency and uni-dimensionality will thus be carried out by computing and plotting (q_{comp}) against (q_{emp}) and relating the expected linearity of this plot to the expected uni-dimensionality of the factor analysis of the same matrix.

8.2.2 *Unit of measurement*

Ekman (ibid.) has shown that the generalized ratio scaling method earlier used by me in Exp. I and II gives two scales with the same

unit of measurement. In Exp. I and II, six silent velocities constituted the stimuli set used as entries for rows and six loaded velocities constituted the set for columns. In those two experiments the subjects were instructed to use the silent velocities as reference stimuli. To make sure that the difference found between silent and loaded scale values was not an artifact of the method for collecting the ratios—it may introduce response-bias—the disposition of the matrices was switched in Exp. VII to X.

This switch of stimuli sets also introduces a change in the unit of measurement which in turn will have consequences for the comparability between the different experiments. As non-identical sets of stimuli appear as row and column entries this switch may be seen as analogous to the change of standard stimulus made in Exp. III to VI using the method of magnitude estimation.

In order to illustrate what happens, let me compare Exp. I to the proposed Exp. VII.

Exp. I was carried out according to the following plan:

Loaded velocity

	$B_1 \ldots\ldots B_6$
A_1	$A_1/_{B_1}\ A_1/_{B_6}$
⋮	
A_6	

ent
ocity

$$\Sigma r_1 = A_1 \cdot \frac{B_2B_3B_4B_5B_6 + \ldots\ldots + B_1B_2B_3B_4B_5}{B_1B_2B_3B_4B_5B_6} = k_1$$

$$\Sigma r_6 = A_6 \cdot k_1$$

$$\Sigma c_1 \ldots\ldots \Sigma c_6 \quad T = (A_1 + \ldots\ldots + A_6) \cdot k_1$$

$$\Sigma c_1 = {}^1/_{B_1} \cdot (A_1 + \ldots A_6) \quad \Sigma\frac{T}{c_1} = \frac{k_1 (A_1 + \ldots\ldots + A_6)}{{}^1/_{B_1}(A_1 + \ldots\ldots + A_6)} = B_1 \cdot k_1$$

$$\Sigma c_6 = {}^1/_{B_6} \cdot (A_1 + \ldots + A_6) \quad \Sigma\frac{T}{c_6} = B_6 \cdot k_1$$

Thus, k_1 is the unit of measurement for both rows and columns, i.e. for both the silent scale and the loaded scale.

Now, if I switch the sets of stimuli between rows and columns, as is done in Exp. VII, the following result is arrived at:

Silent velocity

Loaded velocity	A_1	....	A_6
B_1	$B_1/_{A_1}$		$B_1/_{A_6}$
:			
B_6			

$$\Sigma r_1 = B_1 \cdot \frac{A_2A_3A_4A_5A_6 + \ldots + A_1A_2A_3A_4}{A_1A_2A_3A_4A_5A_6} = k_2$$

As seen, the unit of measurement is changed from k_1 to k_2 and if a sensory interaction effect is at work, viz. $A_i \neq B_i$, then $k_1 \neq k_2$. Assuming all other parameters to be constant, an indirect way of illustrating the effect would thus be to plot the silent scales from Exp. I and VII against each other—and do the same thing with the loaded scales. If the difference between k_1 and k_2 is the only one between the experiments, both plots should show the same deviation from the 45° slope. Similarly the proposed Exp. VII and IX have the same unit of measurement and the corresponding plots should in this case be linear of a 45° slope. (Similarly, if the intermittent auditive frequencies of 12 and 5 per second used in Exp. I and II function alike, no difference in k should be found. This could be tested ad hoc by doing the plot described above. This plot shows a very small systematic deviation from 45° slope.)

The change in unit of measurement described above changes the scales by a constant and full comparability could thus be restored by doing either a linear transformation, or by inverting one of the matrices.

8.3 *Planning and common procedure of Experiments VII to X*

The four experiments to be reported were planned and carried out in the following manner. Row and column stimuli sets were switched as compared to Exp. I and II and instructions changed accordingly. The generalized ratio scaling method was used throughout.

Experiment VII is a direct replication of Exp. I, ratio scaling of silent and loaded (12 per second) velocity. The same analyses as for Exp. I were done. In addition q_{comp} was calculated and plotted against q_{emp}.

Experiment VIII was ratio scaling of silent velocity and intermittent auditive frequency (2—12 per second). The aims of this experiment were: 1) To see if subjects find it natural to handle a common attribute in silent velocity and intermittent frequency (both stimuli being components of loaded velocity). 2) To test the group response matrix for unidimensionality and internal consistency. 3) To see if the use of intermittent frequency as reference stimuli set as predicted changes the resulting scales within a linear transformation. It was thought that if subjects judge the same attribute in silent and loaded velocity (which has not been shown yet), they ought to be able to compare and give ratios using this same attribute when a pure auditive stimulation and a visual stimulation are given together, each being part of the combined stimulus pattern presented as loaded velocity. From these data q_{comp} were computed and plotted against q_{emp}. A factor analysis of the group matrix is done and the results from these two analyses are interpreted in relation to each other.

Experiments IX and X are replications of Exp. VII and VIII respectively with the difference that the same group of subjects went through the conditions described under Exp. VII and VIII in random order. Exp. IX was analysed as Exp. VII and Exp. X was analysed as Exp. VIII.

The instructions were brief, asking the subject to give the ratio of the speeds of the two stimuli patterns presented (indicating the direction of the relation). Each subject was allowed to see (and hear) each stimuli combination as often as (and for as long time as) she desired. The same six velocities as before were used. The position of the loaded stimulus was varied at random between the left and right positions as well as the type of stimulus presented first in each pair. Instead of a random permutation of the 36 stimuli pairs (the randomization procedure employed in Exp. I and II) the 6 stimuli pairs in each row were permuted and one fixed

permutation for columns was used throughout. It was thought that the subject's chances of learning the presentation pattern were not increased by this procedure as each experimental session was shortened.

Each stimuli pair was judged four times. External conditions were as described in Exp. I and II, Chapter 6. The same apparatus as in Exp. I and II was used, see Appendix I. As no great difference was noticed between the intermittent frequencies of 12 and 5 per second, only 12 per second was used in these experiments.

8.4 *Subjects*

The subjects used in these experiments were all female students of psychology in the age range 20—24 years. As my main interest was to study effects of intermittent auditive stimulation on the perception of velocity, differences between sexes were of secondary interest. Female subjects had shown a more marked susceptibility in the previous experiments and were selected for that reason.

18 subjects participated in the experiments (none had previously participated in Exp. I to VI). In Experiment VII, 6 subjects participated. In Experiment VIII, 6 subjects did ratio scaling of silent velocity and intermittent auditive frequency (2, 4, 6, 8, 10 and 12 per second). Experiments IX and X are replicates of Exp. VII and VIII respectively, using 6 subjects, 3 starting with Exp. IX, 3 starting with Exp. X. Exp. IX and X were done on different days.

8.5 *Experiments VII and IX*

8.5.1 *Procedure*

Both experiments are replicates of Exp. I, except that stimuli sets for rows and columns were switched. Treatments and external conditions were as described in Chapter 6. In Exp. VII 6 subjects participated and in Exp. IX 6 other subjects participated, who in addition was used in Exp. X before or after Exp. IX.

Table 8.1. Experiment VII

Individual scale values from the generalized ratio scaling method. (Intermittent frequency 12 per second.) a) Silent velocity. b) Loaded velocity.

a)

Subject No.	20	36	60	90	113	153	r.p.m.
1 f	2.07	4.33	7.52	14.02	18.89	33.71	
2 f	2.95	4.29	7.38	8.40	9.85	14.08	
3 f	2.81	4.45	6.95	9.65	10.43	13.22	
4 f	2.77	4.68	6.35	9.52	10.90	14.08	
5 f	2.61	4.18	6.88	9.61	13.29	18.66	
6 f	1.88	5.03	9.91	14.89	17.43	22.89	

b)

Subject No.	20	36	60	90	113	153	r.p.m.
1 f	2.71	3.99	8.05	15.27	23.57	28.00	
2 f	3.20	4.94	6.73	9.04	11.56	15.35	
3 f	3.07	4.78	6.96	11.11	11.09	13.35	
4 f	2.96	4.25	6.73	8.64	11.42	14.28	
5 f	2.91	3.99	7.78	11.07	13.22	18.70	
6 f	2.86	4.28	8.80	16.02	22.72	19.93	

8.5.2 *Results*

In each individual matrix, the geometric mean of the four ratios in each cell was computed. The individual scales were computed as described in Chapter 6 and are given in Table 8.1 for Exp. VII and Table 8.3 for Exp. IX. Inspection of tables 8.1 and 8.3 and individual S-R plots do not reveal any gross irregularities in the curves (except for an earlier noticed inter-individual variation from negatively to positively accelerated functions).

The plots between silent and loaded scale values are given in Diagram 8.1 (Exp. VII) and Diagram 8.3 (Exp. IX). There is agreement between plots from the two experiments and both plots exhibit the earlier found deviation from 45° slope in positive direction indicating an over-estimation of loaded velocity.

Table 8.2. Experiment VII

Difference between loaded and silent scale values for each subject. $\overline{\text{Diff.}}$ = mean difference computed over 6 female subjects. $\overline{\text{Diff.}}\%$ = $\overline{\text{Diff.}}$ given in percent of respective group mean silent scale value.

Subject No.	20	36	60	90	113	153	r.p.m.
1 f	0.64	—0.34	0.53	1.25	4.68	—5.71	
2 f	0.25	0.65	—0.65	0.64	1.71	1.27	
3 f	0.26	0.33	0.01	1.45	0.66	0.13	
4 f	0.19	—0.43	0.38	—0.88	0.52	0.20	
5 f	0.30	—0.19	0.90	1.46	—0.07	0.04	
6 f	0.98	—0.75	—1.11	1.13	5.29	—2.96	
$\overline{\text{Diff.}}$	0.44	—0.12	0.01	0.84	2.13	—1.17	
$\overline{\text{Diff.}}\%$	17.46	—2.67	0.11	7.63	15.81	—6.02	

Table 8.3. Experiment IX

Individual scale values from the generalized ratio scaling method. (Intermittent frequency 12 per second.) a. Silent velocity. b. Loaded velocity.

a)

Subject No.	20	36	60	90	113	153	r.p.m.
13 f	2.30	3.89	7.29	12.83	16.96	28.63	
14 f	2.22	4.87	8.07	11.03	13.56	17.61	
15 f	2.52	4.07	6.30	10.96	16.59	21.39	
16 f	3.24	4.97	6.32	7.04	9.27	12.12	
17 f	2.21	3.79	8.32	14.62	18.77	24.55	
18 f	2.21	5.24	7.33	10.61	13.48	19.37	

b)

Subject No.	20	36	60	90	113	153	r.p.m.
13 f	2.28	4.74	8.05	14.62	18.59	25.00	
14 f	2.83	4.46	7.62	10.55	14.39	20.92	
15 f	2.59	3.63	7.85	11.34	19.08	18.40	
16 f	3.72	4.42	6.22	9.01	11.28	11.90	
17 f	1.94	4.56	10.58	10.30	19.19	25.76	
18 f	3.01	4.33	8.38	12.56	15.39	22.77	

Table 8.4. Experiment IX

Difference between loaded and silent scale values for each subject. $\overline{\text{Diff.}}$ = mean difference computed over 6 female subjects. $\overline{\text{Diff.}}\%$ = $\overline{\text{Diff.}}$ given in percent of respective group mean silent scale value.

Subject No.	20	36	60	90	113	153 r.p.m.
13 f	—0.02	0.85	0.76	1.79	1.63	—3.63
14 f	0.61	—0.41	—0.45	—0.48	0.83	3.31
15 f	0.07	—0.44	1.56	0.38	2.49	—2.99
16 f	0.48	—0.55	—0.10	1.97	2.01	—0.22
17 f	—0.27	0.77	2.26	0.68	0.42	1.21
18 f	0.80	—0.91	1.05	1.95	1.91	3.40
$\overline{\text{Diff.}}$	0.28	—0.12	0.84	1.05	1.55	0.18
$\overline{\text{Diff.}}\%$	11.43	—2.68	11.55	9.39	10.49	0.87

Table 8.2 (Exp. VII) and Table 8.4 (Exp. IX) give the difference between loaded and silent individual scale values. The means of these differences are illustrated in Diagrams 8.2 and 8.4. A close agreement between Exp. VII and IX is found, both experiments exhibiting the bimodal relative effect curves earlier found in Exp. I. For comparison the relative effect curves from Exp. I are plotted in Diagram 8.2.

In Diagram 8.5 and 8.6 are given the plots between computed and empirical ratios, for Exp. VII and IX respectively. Both diagrams show a close agreement to the 45° slope.

In Tables 8.5 and 8.6 are given the results from the factor analysis.

In both Exp. VII and IX more than 99 % of the variance of the group matrices are described by the first latent root. According to the criteria implicit in the methods used both experiments yield unidimensional and consistent matrices. It is, however, possible that the methods used are insensitive for certain types of bias—see e.g. Sjöberg (1965).

Diagrams 8.7, 8.8 and 8.9 show plots between silent/silent and loaded/loaded scales from Exp. I, VII and IX illustrating the effect of a change in the unit of measurement. In Diagram 8.7

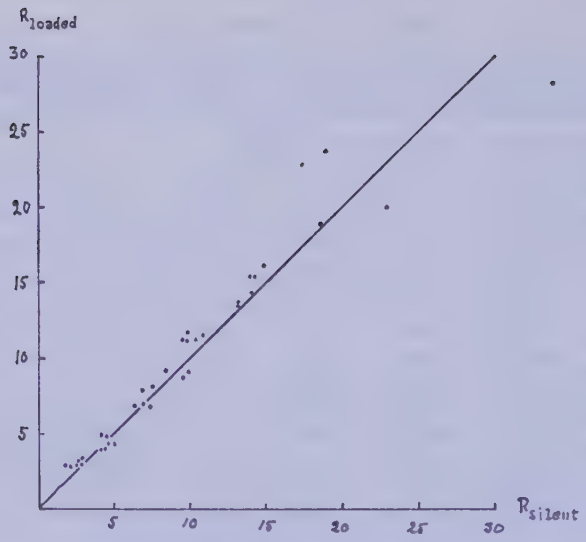


Diagram 8.1 Experiment VII. Plot of the relation between silent and loaded scale values. Number of subjects = 6.

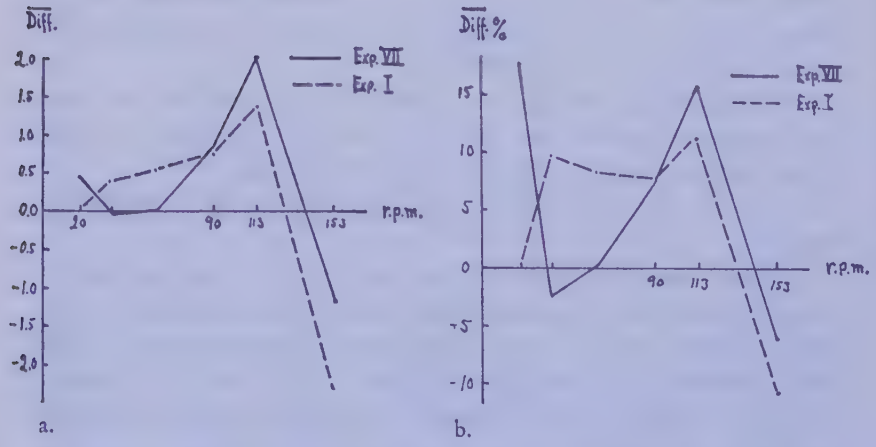


Diagram 8.2 Experiment VII. (Experiment I given as a comparison.)
a. Compared velocities plotted against mean difference between loaded and silent scale values, (Diff.). b. Diff. given in percent of mean silent scale value, (Diff %).

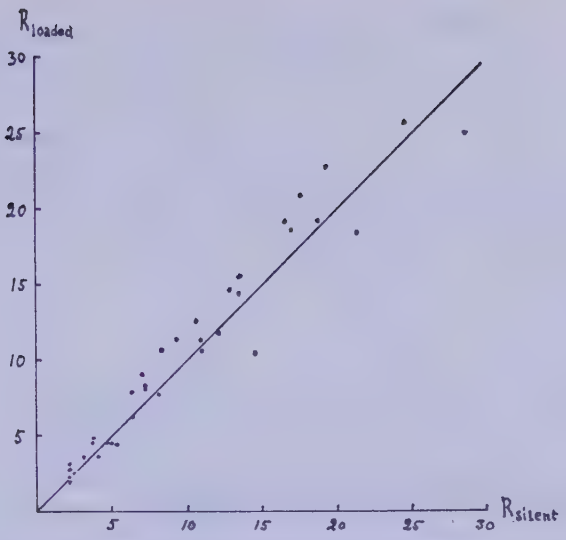


Diagram 8.3 Experiment IX. Plot of the relation between silent and loaded scale values. Number of subjects = 6.

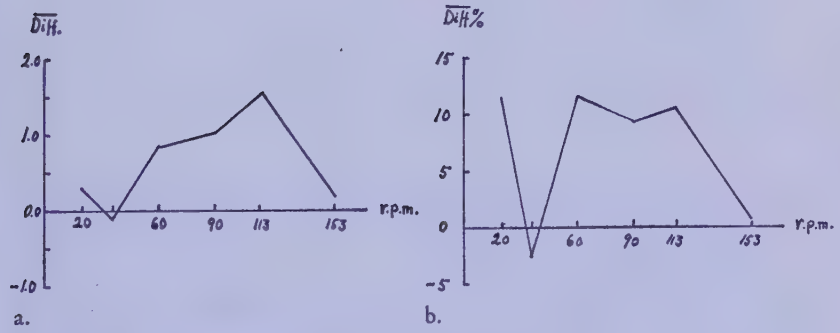


Diagram 8.4 Experiment IX.
a. Compared velocities plotted against mean difference between loaded and silent scale values, (Diff.). b. Diff. given in percent of mean silent scale value, (Diff %).

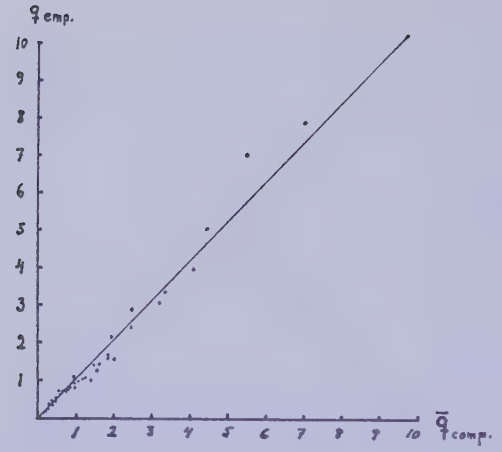


Diagram 8.5 Experiment VII. $\bar{q}_{comp.}$ plotted against $q_{emp.}$ $\bar{q}_{comp.}$ computed on the mean matrix of 6 subjects.

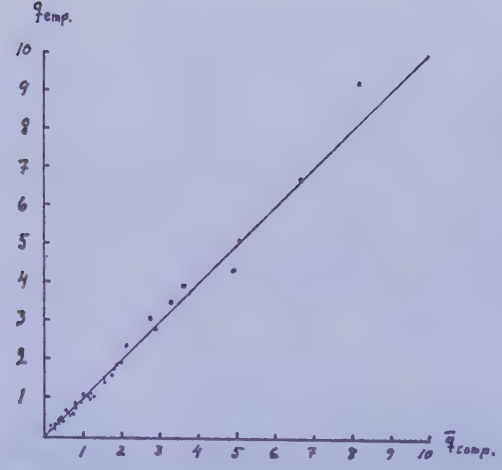


Diagram 8.6 Experiment IX. $\bar{q}_{comp.}$ plotted against $q_{emp.}$ $\bar{q}_{comp.}$ computed on the mean matrix of 6 subjects.

Table 8.5. Experiment VII

Factor analysis of group data (artihmetic mean of individual geometrical cell means).
Number of subjects = 6. Trace = 216.1565.

Latent root No.	Absolute value of latent root	Cumulative sum of latent root	Cumulative proportion of trace
1	215.740	215.740	0.9981
2	0.261	216.001	0.9993
3	0.122	216.123	0.9998
4	0.032	216.155	1.0000
5	0.002	216.156	1.0000
6	0.000	216.156	1.0000

Table 8.6. Experiment IX

Factor analysis of group data (artihmetic mean of individual geometrical cell means).
Number of subjects = 6. Trace = 252.8417.

Latent root No.	Absolute value of latent root	Cumulative sum of latent root	Cumulative proportion of trace
1	252.246	252.246	0.9976
2	0.509	252.755	0.9996
3	0.056	252.811	0.9999
4	0.023	252.834	1.0000
5	0.006	252.840	1.0000
6	0.001	252.842	1.0000

Experiments VII and IX are transformed to the same unit by inverting the group matrix. As seen from the plot, linearity of 45° slope is not restored. However different subjects are used in the experiments compared. Successive ratios between values from Exp. I and Exp. VII and IX respectively lie fairly constant around 1.13 except for the highest scale values (Diagram 8.8.). Although different subjects participated in the three experiments the diagrams show that agreement to 45° slope is better between Exp. VII

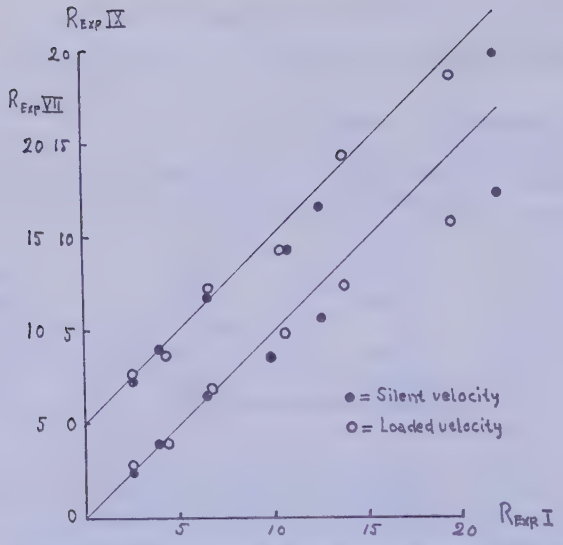


Diagram 8.7 Silent and loaded scales from Experiment I plotted against scales from inverted group matrices of Experiment VII and Experiment IX.

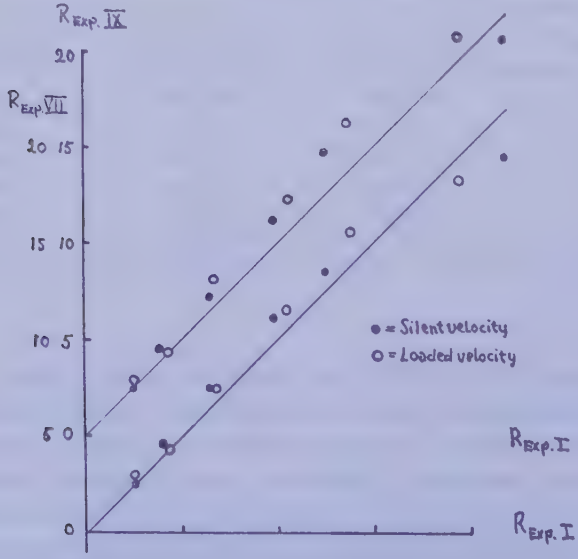


Diagram 8.8 Silent and loaded scales from Experiment I plotted against corresponding scales from inverted group matrices from Experiment VII and Experiment IX showing the effect of a change in the unit of measurement.

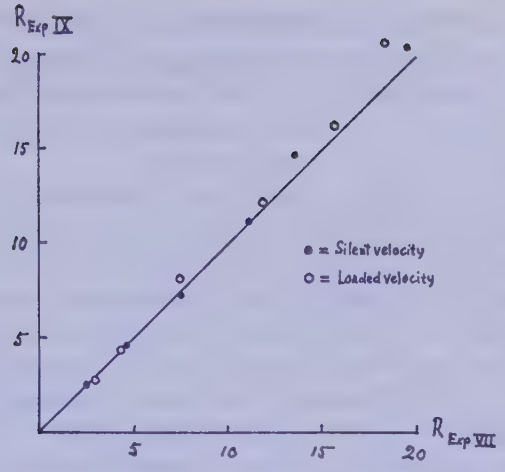


Diagram 8.9 Silent and loaded scales from Experiment VII and IX plotted against each other.

and IX than either of I/VII or I/IX. This is at least an indication that the change of the unit of measurement only affects the scales by a linear transformation. However, the upper end of the scales seem to be affected differently from the rest.

The results above should be seen in relation to the discussion by Sjöberg (ibid.). He points out that the model $q_{ij} = R_i/R_j$ has been found inadequate and proposes a model $q_{ij} = R_{iv}/R_{js}$ (where R_{iv} is the subjective value of stimulus i when it occurs as variable and R_{js} the subjective value of stimulus j when it occurs as standard) taking care of response bias occurring because a stimulus is different when the stimulus appears as standard or variable respectively. The experiments carried out so far indicate that a standard/variable effect is at work in ratio estimation. The different form of the relative effect curves from ratio estimation and magnitude estimation and the similarity of the relative effect curves from ratio estimation with silent and loaded velocity as standard point in this direction. However the finding that the unit of measurement is not the same when silent and loaded velocity are used as standard, indicates that the loading has an effect in

itself. The results from magnitude estimation (where the standard/variable effect is not at work) point in the same direction. In chapter 9 an experiment with ratio estimation will be reported where an attempt will be made to separate the standard/variable effect from the sensory interaction effect.

In Table 8.7 the effect of repetition of judgement is illustrated. Group scales from the first and fourth judgement are compared for silent and loaded velocity for Exp. VII and IX. Although different subjects are used in the two experiments there is fairly good agreement in the results. As found earlier in Chapter 6 and 7, the loaded scale values change more over judgements than do the silent scale values. Moreover, the same systematic pattern of change from low to high velocity is found in both of the present experiments. For low and medium velocities the change is positive for the silent scale values and negative for the loaded scale values. At the highest velocity the change of the loaded scale values is positive or less negative than the negative change of the silent scale values. In other words the change could be roughly described by saying that the loaded scale is rotated in a counter clockwise direction more than the silent scale is rotated in clockwise direction. This description roughly fits the findings from Exp. I to VI also.

The conventional psychophysical power function $R = c(S-S_0)^n$ has been fitted to each individual scale and the group scales using a computer program (see Ottander et al. 1964). The calculated parameters are given in Appendix II. The fitting of the above mentioned function was originally done in an attempt to predict and describe what happens when a subject is scaling velocity that is loaded with an intermittent auditive frequency. Many problems connected with the issue of curve-fitting did, however, occur in these and also in the next two experiments to be reported. A discussion of this issue will therefore be taken up in Appendix II.

8.6 *Experiments VIII and X*

8.6.1 *Procedure*

In Exp. VIII, 6 female subjects did ratio scaling of intermittent auditive frequency and silent velocity. The intermittent frequencies

Table 8.7. Experiments VII and IX

The effect of repetition of judgement on group scale values from silent and loaded velocity.
a) Experiment VII. b) Experiment IX.

a)

Silent velocity	20	36	60	90	113	153	r.p.m.
1:st judgement	2.50	4.18	7.20	10.19	13.80	19.50	
4:th judgement	2.46	4.49	7.24	10.82	12.31	16.91	
(4:th—1:st)	—0.04	0.31	0.04	0.63	—1.49	—2.59	
Diff. in % of silent scale value	—1.60	7.41	0.56	6.18	—10.79	—13.28	
Loaded velocity	20	36	60	90	113	153	r.p.m.
1:st judgement	3.09	4.61	7.64	12.84	15.24	19.77	
4:th judgement	2.83	4.25	7.17	10.04	13.55	18.29	
(4:th—1:st)	—0.28	—0.36	—0.47	—2.80	—1.69	—1.48	
Diff. in % of silent scale value	—9.06	—7.81	—6.15	—21.81	—11.09	—7.49	

b)

Silent velocity	20	36	60	90	113	153	r.p.m.
1:st judgement	2.44	4.22	6.82	11.44	14.24	20.57	
4:th judgement	2.36	4.43	6.92	11.37	14.91	19.59	
(4:th—1:st)	—0.08	0.21	0.10	—0.07	0.67	—0.98	
Diff. in % of silent scale value	—3.28	4.98	1.47	—0.61	4.70	—4.76	
Loaded velocity	20	36	60	90	113	153	r.p.m.
1:st judgement	3.71	4.27	8.07	12.68	18.85	17.64	
4:th judgement	2.55	4.26	7.78	12.58	17.08	20.00	
(4:th—1:st)	—1.16	—0.01	—0.29	—0.10	—1.77	2.36	
Diff. in % of silent scale value	—31.26	—0.23	—3.59	—0.79	—9.39	13.38	

Table 8.8. Experiment VIII

Individual scale values for silent velocity (a) and intermittent frequency (b).

a)

Subject No.	20	36	60	90	113	153 r.p.m.
7 f	2.52	3.92	6.09	7.54	7.87	11.38
8 f	1.69	1.90	2.89	3.72	5.30	5.92
9 f	3.56	4.28	5.07	6.88	6.75	9.01
10 f	1.22	2.23	3.64	4.91	5.02	6.44
11 f	3.10	4.20	5.38	7.07	7.11	9.60
12 f	0.95	1.37	2.16	2.95	4.72	6.96

b)

Subject No.	2	4	6	8	10	12 per sec.
7 f	2.60	6.09	7.56	7.80	9.93	11.04
8 f	2.30	4.81	7.24	9.96	14.91	21.42
9 f	3.12	5.35	6.10	6.60	10.71	11.89
10 f	3.19	5.21	5.79	6.88	9.16	14.75
11 f	3.06	5.81	5.88	7.01	10.10	11.15
12 f	3.17	5.51	6.92	7.86	8.00	9.41

were 2, 4, 6, 8, 10 and 12 per second. All other treatments and external conditions were as described earlier.

In Exp. X, 6 other female subjects participated. Exp. X is a replication of Exp. VIII (although the 6 subjects in addition was used in a replication of Exp. VII before or after Exp. X).

8.6.2 *Results*

Individual scales for silent velocity and intermittent frequency were computed as described in Exp. VII and are given in Table 8.8 (Exp. VIII) and Table 8.9 (Exp. X). All subjects found it natural and easy to carry out the instructions, i.e. to give a ratio of *the speeds* of the intermittent frequency to the silent velocity. Inspection of the tables and *S-R* plots of the individual scales

Table 8.9. Experiment X

Individual scale values for silent velocity (a) and intermittent frequency (b).

a)

Subject No.	20	36	60	90	113	153 r.p.m.
13 f	0.85	1.48	2.28	3.41	4.78	6.71
14 f	2.16	2.89	5.36	7.22	7.80	10.74
15 f	1.89	1.60	3.36	4.28	7.35	19.78
16 f	3.80	4.75	5.27	5.69	5.87	6.27
17 f	2.98	4.20	4.19	5.36	9.57	15.91
18 f	3.13	3.32	5.67	7.55	8.66	14.21

b)

Subject No.	2	4	6	8	10	12 per sec.
13 f	2.34	5.02	7.50	9.43	12.92	17.74
14 f	2.15	5.97	8.49	10.48	11.52	14.82
15 f	2.76	5.28	5.51	8.09	12.11	16.58
16 f	4.63	5.81	5.87	5.84	6.78	8.16
17 f	2.49	4.56	7.88	9.51	12.27	15.41
18 f	2.55	5.79	6.13	8.72	11.85	13.77

reveal that the scales of intermittent frequency for all subjects exhibit a break occurring around the intermittent frequency of 8 per second. As an illustration the group curves and two individual curves from each experiment and condition are given in Diagrams 8.10, 8.11. The breaks also occur, however, in the silent velocity curves. They are more marked in Exp. VIII than in Exp. X, but the subjects in Exp. X who started with this experiment (subjects No. 15, 16 and 18) show more marked breaks than does the rest of the group. In Exp. I, VII and IX no such phenomenon was encountered. In the case of intermittent auditive frequency the breaks might be thought of as reflecting the breakdown of the subjects' counting ability. The S-R curves in Diagram 8.12 e to h, may thus each contain two scales reflecting two modes of perceiving intermittent frequency. The curves of silent velocity

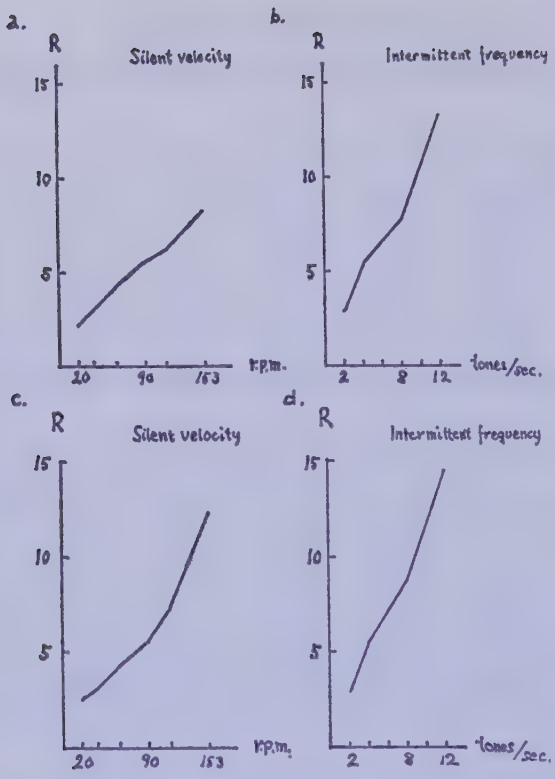


Diagram 8.10 S-R plots of group scales from silent velocity and intermittent frequency.
a, b from Experiment VIII. c, d from Experiment X.

are more difficult to explain. Maybe the low intermittent frequencies induce a "counting set" making the subjects apt to perceive the frequency of the circular motion? The possibility of counting should then break down when the moving spot is fused at high velocities.

This two-dimensional interpretation is, however, clearly refuted by the uni-dimensionality of the pooled group matrix shown by the factor analysis reported below. No straightforward explanation for the observed phenomenon could be given at this stage.

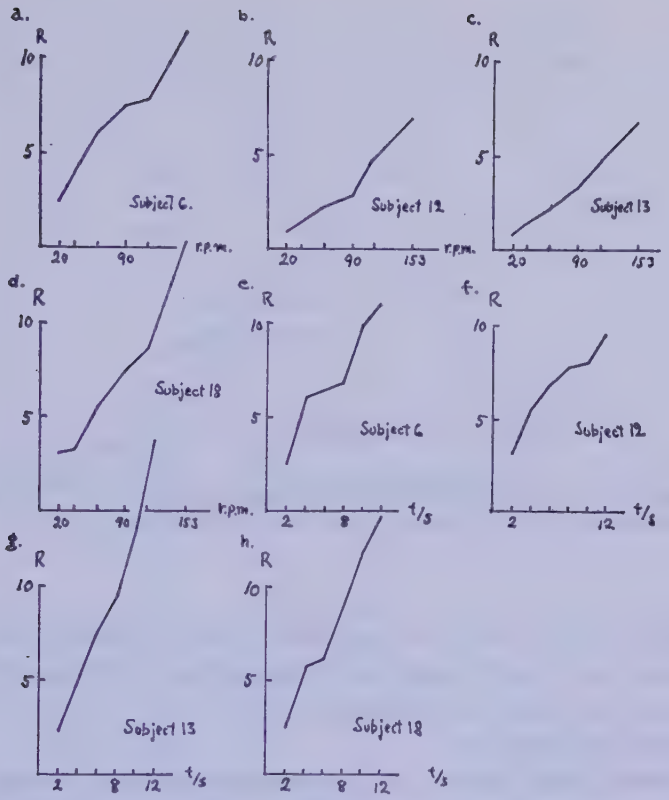


Diagram 8.11 Experiment VIII and X. Individual S-R curves illustrating the break occurring in these experiments.
a, b, c, d = silent velocity. e, f, g, h = intermittent frequency.

In Diagram 8.12 are given plots between Exp. VIII, X and Exp. VII, illustrating the effect of change in unit of measurement. The change should have the form of a linear transformation by a constant. If, however, successive ratios of pairs of R-values for VII/VIII and VII/X are computed this ratio continuously increases from about 1 to 2 over the scale. This implies that something else, beside the change of unit of measurement, has occurred when intermittent auditive frequency is scaled together with

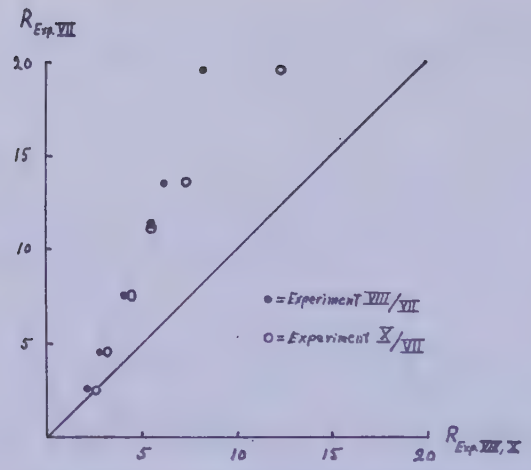


Diagram 8.12 Plot of silent mean scales from Experiment VII, VIII and X illustrating the effect of a change in the unit of measurement.

silent velocity. It may be remembered that the change of unit occurred according to prediction between Exp. I, VII and IX in spite of the fact that different subjects participated in the different experiments.

These findings could be seen in connection with the findings of breaks in the curves mentioned above. All that could be said at present is that subjects apparently behave differently when they scale silent and loaded velocity as compared to when they scale silent velocity and intermittent frequency.

These findings also restrict the range of application of findings from the tests of internal consistency and dimensionality to be considered below. Even if it turns out that subjects do function consistently and judge one and the same dimension when silent velocity and intermittent frequency are scaled together, this is not necessarily true when silent and loaded velocity are scaled together.

Diagram 8.13 shows plots between group scales from Exp. VII and X. Agreement with a 45° slope is far from perfect. The different subjects participating in the two experiments may be

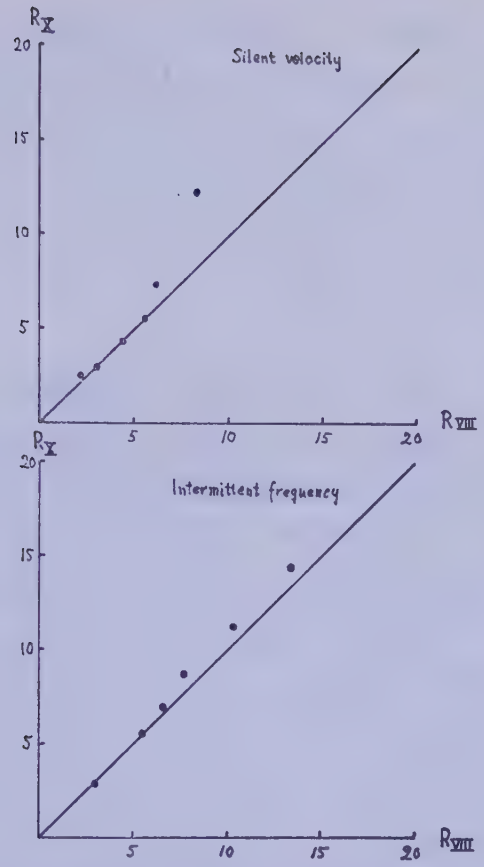


Diagram 8.13 Plot of silent mean scale values (a.) and intermittent frequency mean scale values (b.) from Experiment VIII and X carried out with the same unit of measurement.

one cause (previously this has not played any crucial role). Another is that the subjects in Exp. X in addition went through the scaling of silent and loaded velocity. If the mean scales of the three subjects starting with Exp. X are plotted against the mean scales of Exp. VIII, the plot for intermittent frequency shows a better agreement with a 45° slope and that for silent velocity a worse one. In Diagrams 8.14 and 8.15 are shown the plots between

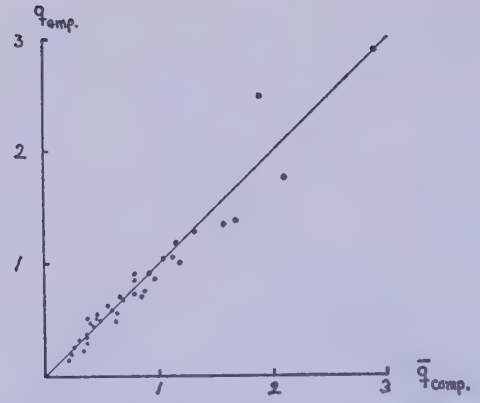


Diagram 8.14 Experiment VIII. Ratio scaling of silent velocity and intermittent frequency. Plot between the mean of computed ratios, $\bar{q}_{comp.}$ and empirical ratios, $q_{emp.}$ $\bar{q}_{comp.}$ computed on the mean matrix of 6 subjects.

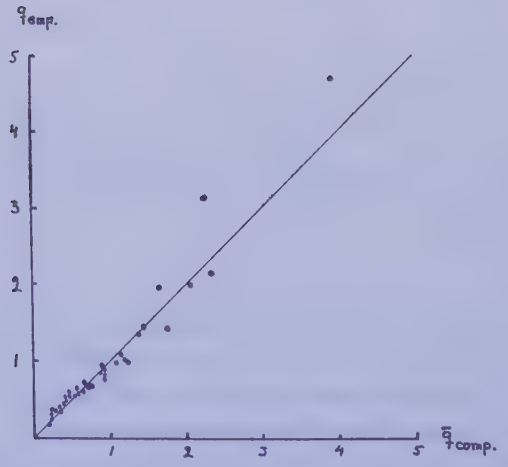


Diagram 8.15 Experiment X. Ratio scaling of silent velocity and intermittent frequency. Plot between the mean of computed ratios, $\bar{q}_{comp.}$ and empirical ratios, $q_{emp.}$. $\bar{q}_{comp.}$ computed on the mean matrix of 6 subjects.

Table 8.10. Experiments VIII and X

Factor analysis of pooled data (geometric means) from the two experiments. Number of subjects = 12. Trace = 39.4619.

Latent root No.	Absolute value of latent root	Cumulative sum of latent root	Cumulative proportion of trace
1	39.266	39.266	0.9950
2	0.134	39.399	0.9984
3	0.036	39.436	0.9993
4	0.021	39.457	0.9999
5	0.005	39.462	1.0000
6	0.000	39.462	1.0000

Table 8.11. Experiments VIII and X

Group scales for silent velocity and intermittent auditive frequency. Pooled data from 12 subjects. S = stimulus value. R = directly computed scale values from group matrix (geom. means). R' = scale values computed by factor analysis. $R'' = R'$ linearly transformed by equalizing R_1 and R'_1 ($R' \cdot 5.44$).

Silent velocity				Intermittent auditive frequency			
S	R′	R″	R	S	R′	R″	R
20	0.39	2.14	2.14	2	0.52	2.81	2.81
36	0.50	2.72	2.68	4	1.02	5.53	5.19
60	0.72	3.93	3.99	6	1.23	6.71	6.57
90	0.94	5.11	5.17	8	1.48	8.06	7.92
113	1.17	6.36	6.09	10	1.78	9.66	9.76
153	1.76	9.56	9.30	12	2.76	14.99	14.16

computed and empirical ratios. The plots appear to agree fairly well to 45° slope.

The factor analysis was done on pooled data from Exp. VIII and X. Arithmetic means were computed on the (6 + 6) geometric means in each cell from each individual and a pooled matrix of (6 × 6) geometric/arithmetic means was thus factor analysed. The result of this analysis is presented in Table 8.10 and scales from the factor analysis are compared with the directly computed

scales in Table 8.11. As seen from these tables one and only one dimension is found in the matrix. In these two experiments the subjects appear to judge and scale intermittent frequency and silent velocity consistently and by using one and the same attribute.

It is, however, not possible to assume that the same thing holds true when silent and loaded velocity are scaled together.

The power function $R = c\,(S-S_0)^n$ has been fitted to individual scales and group scales from Exp. VIII and X. The calculated parameter-values are given and discussed in Appendix II.

8.7 *Discussion of results from Experiments VII to X*

Exp. VII and IX, were replications of Exp. I, differing from the latter only in the unit of measurement. The aim of these two experiments were 1) to verify the modified working hypothesis that the difference curve between corresponding loaded and silent scale values is bimodal, 2) that a change in the unit of measurement changes the scales linearly and 3) that the effect of the intermittent frequency is systematically changed from the first to the fourth judgement instance. In general the results confirm points 1 to 3 and are in line with the findings from Exp. I. As the same stimuli set as in Exp. I was used in these experiments it is impossible to tell at this stage whether the bimodal difference curve is due to the stimuli used, the scaling method or the auxiliary stimulation introduced. The different effect curves found in these experiments and Exp. III to VI do, however, show the influence of the method used.

The unit of measurement should change the scale linearly. Remembering that different subjects participated in Exp. I and VII and IX, the agreement with prediction is good. The deviation of the highest scale values from the predicted values cannot be explained.

The change of effect over judgement instances falls into line with earlier findings from Exp. I to VI. The effect of intermittent stimulation appears to be greatest at the first judgement instance diminishing at the following judgement instances. There is also

some indication that the effect may eventually increase at the fourth instance.

It is still unclear whether the effect of intermittent auditive frequency is to be regarded as a response-bias, i.e. changes in the subjects' perception. Hitherto two scaling methods (both using refined judgement scales susceptible to response-bias) have shown the same general overestimation of loaded velocity. Both methods have further shown a characteristic change of this over-estimation over judgement instances. These findings raise new problems. Could the same over-estimation be measured with a method more free from response bias—e.g. the method of paired comparisons? Could the same change of the over-estimation over judgement instances be shown with this method as well? These questions will be taken up in Chapter 10.

In Exp. VIII and X intermittent auditive frequency was scaled together with silent velocity. The aims of these experiments were in short: 1) To see whether subjects found it natural to judge the same attribute (by instruction called speed) in two qualitatively different stimuli sets. 2) To test the uni-dimensionality and internal consistency of the group matrix. 3) To study the effect of change in the unit of measurement. The subjects found it easy and natural to carry out the instructions. The found uni-dimensionality and the internally consistent group matrix further indicate that they only use one and the same attribute in carrying out these tasks. The individual *S-R* plots for both intermittent frequency and silent velocity exhibit breaks not noticed in the previous experiments. Why these breaks occur is unclear. Tentatively it is suggested that the intermittent frequency may induce the subjects to count frequency as long as this is possible and then shift their method of judging at higher speeds. This two-dimensional interpretation is, however, not confirmed by the factor analysis. Investigations studying subjective counting ability of intermittent frequency (see Plutchick op. cit.) report that the counting curves level off above 5 per second. In these experiments the breaks occur around 8 per second after which the S-R curves turn sharply upward. This difference in finding may have to do with the fact that the referred studies directly instructed the subjects to count

while here they were instructed to give ratios of the speeds of two stimuli. In a study by J. C. Stevens and Shickman (1959) subjects did scale different types of intermittent stimuli. As only group curves were analysed no valid information for the present problem is found. For the present, this problem must be left unsolved.

It was predicted that the unit of measurement should be changed by a constant when intermittent frequency was used as reference stimuli. The results did not confirm this prediction. The comparison of silent scales from Exp. IX and X (using the same subjects) shows that these scales are changed in a more complicated way. Indirectly comparable scales from Exp. VIII yield very much the same result. No explanation could be given to this finding either. All that could be said is that subjects behave differently when they scale intermittent frequency together with silent velocity than when they scale silent and loaded velocity.

The two last findings also restrict the applicability of the findings from the factor analysis and the test of internal consistency. For the author it seems an impossible experimental task to show that subjects use the same attribute when they do ratio scaling in the two situations described above.

Chapter 9

An experiment on silent and loaded velocity with the generalized ratio scaling method giving complete ratio matrices

9.1 *Problems*

A satisfactory interpretation of the results in the previous experiments is made difficult by an increasing number of methodological problems that have been encountered. The experiment described in this chapter was planned to gain information on the following points:

1. To give additional information of the relative effect of intermittent auditive frequency on different velocities.
2. To study whether this earlier noted effect in general is increased when presentation time is shortened and fixed.
3. To study whether subjects can carry out a general ratio estimation task consistently when instructed to give ratios $\leqslant 1.00$.
4. To study the effect of a change in the unit of measurement.
5. To discuss an alternative data model (mentioned in Chapter 6) and from this model test a technique of isolating the effect of auditive intermittent frequency (where an assumed additional effect, depending on differential subjective evaluation of a stimulus when it appears as standard and variable, is eliminated).
6. To test the unidimensionality of each individual response matrix predicted from findings on group-matrices in earlier experiments.
7. To test the internal consistency of each individual response matrix predicted from findings on group-matrices in earlier experiments.

Point 1 needs no further comments.

Point 2 is a prediction from the weak indication that the effect of intermittent frequency is greatest at the first presentation. In the previous experiments with ratio scaling, free judgement time was allowed. It is thought that the effect might increase if this time is shortened and fixed (maybe by inducing the subject to behave more naively in the sense that he/she has less time for reflection). The prediction is however cautious as findings both for and against have earlier been cited in Chapter 4.

Point 3 refers to the task the subject is instructed to carry out. The instructions given in the previous experiments with ratio scaling allowed for giving ratios only $\leqq 1.00$, provided the subject indicated which velocity was slowest. (Some subjects did spontaneously give ratios $\leqq 1.00$ and all subjects did in fact use ratios $\leqq 1.00$ in the diagonal cells.) Ratios $\leqq 1.00$ below the diagonal are inverted before scale values are computed. In conventional ratio scaling using identical stimuli sets on both axes of the response matrix this convention usually functions well. (Very often, only half of the matrix is filled with empirical ratios, and the other half assumed to be the reciprocal of the first.) In the generalized ratio scaling method it is necessary to fill the whole matrix with empirical ratios as the matrix is unsymmetrical about the diagonal. The convention of asking only for ratios $\leqq 1.00$ in this case implies that the subject may change the unit of measurement, or—if a variable/standard effect exists—introduces a bias, when giving ratios below the diagonal. The previous experiments are thus carried out according to convention (on the basis of the data model earlier presented) but not strictly according to theory. In the experiment to be described here, the instruction required the subject to give all ratios relative to the same set of reference, or standard, stimuli (as has been done in previous experiments) and to use ratios $\leqq 1.00$. Point 4 deals with a change in the unit of measurement. It is closely related to the following point, 5. If the original data model $q_{ij} = R_i/R'_j$ (where R_i is the ith stimulus of the silent stimuli set and R'_j is the jth stimulus of the loaded stimuli set) is assumed to hold true and if unidentical stimuli sets appear on the two axes of the response matrix—i.e. a sensory interaction effect is assumed to exist,

then (as shown in Chapter 8) the unit of measurement is changed when the subject changes from judging silent velocities relative to loaded velocities goes over to judging loaded velocities relative to silent velocities. By letting both silent and loaded stimuli appear as subsets on both axes as shown below,

	Silent velocities	Loaded velocities
Silent velocities		
Loaded velocities		

each individual matrix will allow computation of 12 separate scales given in three different units of mesasurement. Provided everything is constant except for the changed unit, these scales should agree within a linear transformation. Results not in complete accordance with this prediction were also discussed in Chapter 8.

Point 5 takes up the question of an alternative data model. An alternative model instead of the assumed $q_{ij} = R_i/R'_j$ was proposed in the discussion of Chapter 6. Goude (ibid.) and Sjöberg (ibid.) suggested for the conventional ratio scaling method a model, including the existence of an effect of the subjective value of a stimulus depending on whether it appeared as variable or standard, that could be written

$$q_{ij} = R_{i,v}/R_{j,s}$$

where $R_{i,v}$ stands for the subjective value of stimulus i appearing as variable and $R_{j,s}$ for the corresponding value of stimulus j when it appears as standard.

In the generalized ratio scaling method using nonidentical stimuli sets on the matrix axes the model could be rewritten

$$q_{ij} = R_{i,v}/R'_{j,s}$$

where $R_{i,v}$ is the ith stimulus of the R set appearing as variable and $R'_{j,s}$ is the jth stimulus of the R' set appearing as standard. This model will be tested if the present experiment shows:

a) that the different scales mentioned under point 4 do not agree within a linear transformation,
b) that a relative difference exists between silent and loaded scale values (irrespective of whether this difference is computed as column - row-scales or vice versa) at the same time as the four sets of column - row differences (i.e. standard - variables) do show a uniform pattern.

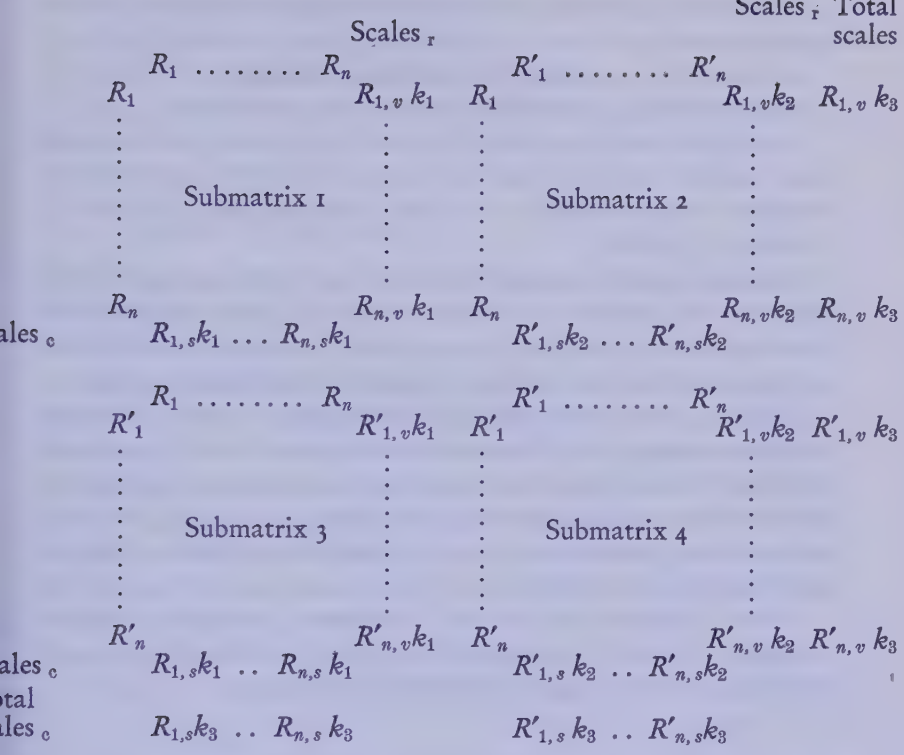
If the Goude-Sjöberg model is applied to the present experiment, the complete matrix below is arrived at:

Standards

Variables	1.	2.
	$R_1\ R_2\ \ldots\ldots\ R_n$	$R'_1\ R'_2\ \ldots\ldots\ R$
R_1	$R_{1,v}/R_{1,s}\ \ldots\ R_{1,v}/R_{n,s}$	$R_{1,v}/R'_{1,s}\ \ldots\ R_{1,v}/R'$
R_2	⋮	⋮
⋮	⋮	⋮
R_n	$R_{n,v}/R_{1,s}$	$R_{n,v}/R'_{1,s}$
R'_1	$R'_{1,v}/R_{1,s}\ \ldots\ R'_{1,v}/R_{n,s}$	$R'_{1,v}/R_{1,s}\ \ldots\ R'_{1,v}/R'$
R_2	⋮	⋮
⋮	⋮	⋮
R'_n	$R'_{n,v}/R_{1,s}$	$R'_{n,v}/R'_{1,s}$
	3.	4.

Scales can be computed in the conventional manner from submatrices 1–4 and (1 + 2), (3 + 4) and (1 + 3), (2 + 4)–see also Chapter 8. The scales from submatrices 1 and 3 are given in unit k_1, the scales from 2 and 4 in k_2 and the remaining four scales from the whole matrix in k_3 ($= k_1 + k_2$).

Besides being given in three different units, the scale values from the different submatrices and the whole matrix also reflect the proposed standard/variable effect and the effect of intermittent auditive frequency:



Column scales in general give the subjective scale values of stimuli functioning as standards and the row-scales reflect these stimuli perceived as variables.

From this is seen that the standard/variable effect is estimated on the silent scales

in submatrix 1 by substracting (column scale - row scale)

in the total matrix by substracting (column scale - row scale)

and for loaded scales

in submatrix 4 by substracting (column scale - row scale)

in the total matrix by substracting (column scale - row scale)

The pooled standard/variable and auditive intermittent frequency effects are estimated

in submatrix 2 by substracting (column scale - row scale)

and in submatrix 3 by substracting (row scale - column scale)

The isolated effect of the auditive intermittent frequency is then given by taking

submatrix 3, row scale – submatrix 1, row scale

and submatrix 4, row scale – submatrix 2, row scale

In the first case silent velocity is used as standard, in the second case loaded velocity is used as standard. In both cases the differences are taken between variable scales and they are given in the units k_1 and k_2.

The same auditive intermittent frequency effect can be estimated from the total matrix by taking (row scale)′ - (row scale) for the variable scales, or by taking (column scale)′ - (column scale) for the standard scales. These last two estimations are given in unit k_3.

Point 6 deals with the dimensionality of each individual response-matrix. It will be tested as in Chapter 8 by doing a factor analysis. The factor analysis is not altered by assuming the Goude-Sjöberg data model mentioned under point 5.

In the programme for the factor analysis only scales from the total matrix are computed.

Point 7 concerns the internal consistency of each individual response matrix. If the original data model is assumed, computed ratios (q_{comp}) may be obtained either by calculating:

1.

$$q_{ji} = q_{kj}/q_{ki}$$
$$k = 1,2, \ldots\ldots n$$

2.

$$q_{ij} = q_{kj} \cdot q_{ih}/q_{kh}$$
$$k \neq i\,;\, h \neq j$$

3.

$$q_{ij} = q_{kj} \cdot q_{ih}/q_{kh}$$
$$k \neq i\,;\, h \neq j$$

4.

$$q_{ij} = q_{kj}/q_{ki}$$
$$k = 1,2, \ldots\ldots n$$

or by considering the total matrix and computing

$$q_{ij} = q_{kj} \cdot q_{ih}/q_{kh}$$
$$k \neq i\,;\, h \neq j$$

throughout. The mean of each one of these computed ratios ($\overline{q}_{comp}$) may then be plotted against the mean of the empirical ratios ($\overline{q}_{emp}$). Provided the matrix (or matrices) is unidimensional, the matrix is internally consistent if this plot is linear.

If the Goude-Sjöberg data model is assumed it is necessary to use the last mentioned equation in all four submatrices. The plot should be linear if the matrices are internally consistent.

As $q_{ij} = q_{ik} \cdot q_{kj}/q_{kh}$ functions for both data models, this equation will be used.

9.2 *Procedure of Experiment XI*

The apparatus used is described in Appendix I. External conditions were as already described.

Six female students of psychology (age range 20–24 years) served as subjects. None had previously participated in sensory interaction experiments or experiments involving velocity, although all of them were familiar with the conventional scaling methods.

The method of generalized ratio scaling was used. The intermittent auditive frequency was 12 per second (pitch 800 cps, loudness 82.5 db.). Four velocities: 60, 90, 113 and 153 r.p.m. were used as stimuli. The response matrix to be filled with empirical ratios was:

		silent velocity				loaded velocity			
		60	90	113	153	60′	90′	113′	153′
silent velocity	60								
	⋮								
	153								
loaded velocity	60′								
	⋮								
	153′								

In each cell four ratios were given. The subject was instructed to give subjective ratios, using the stimulus appearing as column entry as standard or reference stimulus. (E.g. "Give the ratio of the first presented stimulus relative the second one. If the first is larger than the second, give a ratio larger than one.") Before each stimulus pair was presented, an indication of which one was the standard was given. Each stimulus was presented for 2 seconds, the interstimulus interval being negligible:

	Standard	Variable
	2 seconds	2 seconds
or	Variable	Standard

The presentation order was obtained by permutating rows and column of the total matrix. Three subjects received the matrix thus randomized in horizontal order, three in vertical order. The position and sequence of standard/variable and silent/loaded were rotated as before. The experiment was run in one session and no pretrials were given.

9.3 *Results*

In each cell of the individual matrix the geometric mean of the four ratios was computed. The 12 individual scales were computed as described in section 9.1 and are given in Table 9.1 a–f. The group scales are computed from the arithmetic mean matrix of the six individual geometric mean matrices and are given below each group of individual scales in Table 9.1. Individual S-R plots do not reveal any marked irregularities (except for the earlier noticed inter-individual variation from negatively to positively accelerated functions). It is also quite clear that the shortened presentation time used in this experiment does not have any effect in the predicted direction.

In Diagram 9.1 and 9.2 are given the expected combined effect of standard/variable and auditive intermittent frequency from submatrix 2 and submatrix 3 respectively. As seen the direction of the effect is reversed when column - row differences are compared to row - column differences.

The standard/variable effect is illustrated in Diagram 9.3 in which are given the four column - row difference curves. The same tendency is found irrespective of whether the differences are taken between silent/silent, loaded/loaded, silent/loaded or loaded/silent scales. This finding confirms the tentative suggestion from Chapter 6 that the original data model might be inadequate.

A change in the unit of measurement should—provided the original data model holds true—produce a constant deviation from

Table 9.1. Individual scales from Experiment XI

a = submatrix 1 d = submatrix 4
b = submatrix 2 e = submatrices 1 + 2 and 3 + 4
c = submatrix 3 f = submatrices 1 + 3 and 2 + 4

	Subject no	Velocity			
		60	90	113	153
a. *Submatrix 1*					
Rows	1	2.81	3.67	4.12	5.74
Silent	2	2.79	3.59	4.47	6.14
	3	2.02	3.52	4.07	6.15
	4	2.68	3.89	4.73	7.31
	5	2.52	3.77	5.14	8.03
	6	2.63	3.26	4.36	5.41
	Mean	2.54	3.59	4.45	5.41
Columns	1	3.04	3.90	4.30	5.49
Silent	2	2.97	3.52	4.60	6.18
	3	2.90	3.64	4.25	6.89
	4	2.93	3.61	4.37	6.57
	5	2.63	3.79	4.50	7.51
	6	3.22	3.04	4.70	6.77
	Mean	2.94	3.55	4.45	6.51
b. *Submatrix 2*					
Rows	1	2.75	3.86	4.05	5.81
Silent	2	2.78	3.75	4.58	5.82
	3	2.27	3.55	4.45	6.33
	4	2.98	3.80	4.41	7.39
	5	2.63	3.78	4.93	7.43
	6	2.63	3.58	4.88	5.90
	Mean	2.65	3.71	4.52	6.38
Columns	1	2.93	3.58	4.50	6.37
Loaded	2	2.86	3.84	4.69	5.69
	3	2.72	3.74	4.34	7.48
	4	2.87	3.64	4.64	6.19
	5	2.68	3.70	4.49	7.52
	6	2.65	3.96	4.70	6.36
	Mean	2.77	3.74	4.55	6.57

	Subject no	Velocity			
		60	90	113	153
c. *Submatrix 3*					
Rows	1	3.02	4.01	5.02	5.72
Loaded	2	2.73	3.67	4.70	6.06
	3	2.46	3.52	4.45	6.36
	4	2.66	4.14	4.91	6.93
	5	2.65	3.92	4.66	7.98
	6	2.52	3.85	4.74	7.44
	Mean	2.64	3.83	4.73	6.69
Columns	1	3.29	3.28	4.60	5.76
Silent	2	2.91	3.81	4.46	5.87
	3	3.05	3.54	4.20	6.58
	4	2.98	3.66	4.45	5.98
	5	2.77	3.78	4.37	6.85
	6	2.75	3.61	4.46	7.35
	Mean	2.95	3.60	4.41	6.38
d. *Submatrix 4*					
Rows	1	2.90	3.76	4.49	5.64
Loaded	2	2.84	3.79	4.55	5.90
	3	2.44	3.57	4.43	6.24
	4	2.82	3.87	4.63	6.88
	5	2.68	4.31	4.65	6.52
	6	2.55	3.92	4.62	6.48
	Mean	2.68	3.85	4.56	6.25
Columns	1	3.10	3.57	4.30	6.10
Loaded	2	2.95	3.86	4.48	5.59
	3	2.98	3.62	4.37	6.27
	4	2.87	3.63	4.68	6.16
	5	2.77	3.54	4.55	7.28
	6	2.85	3.57	4.85	6.16
	Mean	2.91	3.63	4.55	6.23

	Subject no	Velocity			
		60	90	113	153
e. *Submatrices*					
1 + 2	1	5.56	7.53	8.17	11.54
Rows	2	5.58	7.34	9.06	11.96
Silent	3	4.29	7.07	8.52	12.47
	4	5.66	7.70	9.14	14.70
	5	5.15	7.55	10.08	15.46
	6	5.26	6.85	9.25	11.32
	Mean	5.19	7.30	8.98	12.73
3 + 4	1	5.92	7.77	9.51	11.36
Rows	2	5.57	7.46	9.25	11.96
Loaded	3	4.90	7.08	8.89	12.60
	4	5.47	8.02	9.55	13.81
	5	5.33	8.22	9.31	14.51
	6	5.08	7.77	9.37	13.93
	Mean	5.32	7.68	9.29	12.94
f. *Submatrices*					
1 + 3	1	6.26	7.00	8.79	11.12
Columns	2	5.87	7.31	9.04	12.02
Silent	3	6.02	7.25	8.54	13.60
	4	5.87	7.22	8.76	12.44
	5	5.27	7.40	8.67	14.01
	6	5.93	6.68	9.18	14.23
	Mean	5.88	7.13	8.83	12.84
2 + 4	1	6.09	7.24	8.89	12.62
Columns	2	5.81	7.71	9.18	11.29
Loaded	3	5.62	7.28	8.61	13.49
	4	5.78	7.31	9.38	12.43
	5	5.57	7.41	9.25	15.14
	6	5.47	7.46	9.50	12.44
	Mean	5.69	7.39	9.12	12.83

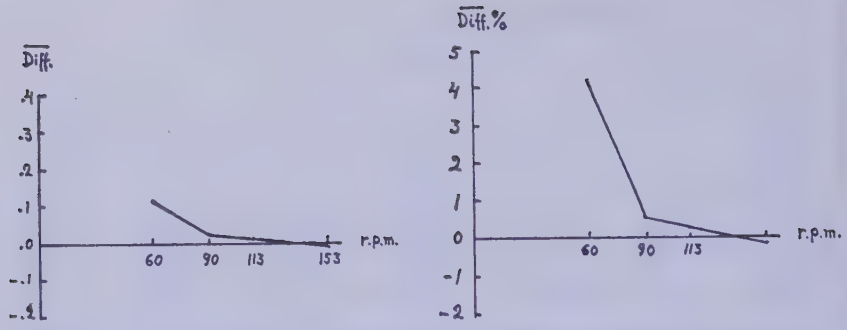


Diagram 9.1 Experiment XI, submatrix 2. Difference between scale values from loaded—columns and silent—rows.

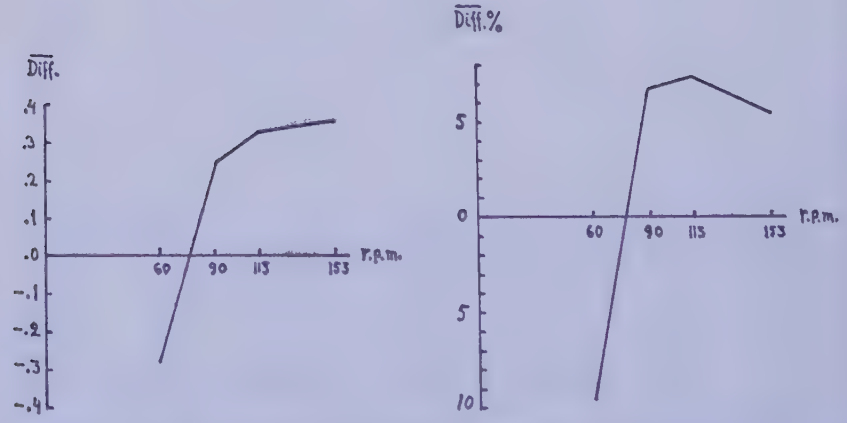


Diagram 9.2 Experiment XI, submatrix 3. Difference between scale values from loaded—rows and silent—columns.

45° linearity, if scales measured in two units (k_1,k_2; k_1,k_3 or k_2,k_3) are plotted against each other. Two examples are given in Diagram 9.4. As shown the prediction is not convincingly confirmed. There is a slight tendency for the higher scale values to show a greater change. This is a further indication, although weak, that the original data model is inadequate.

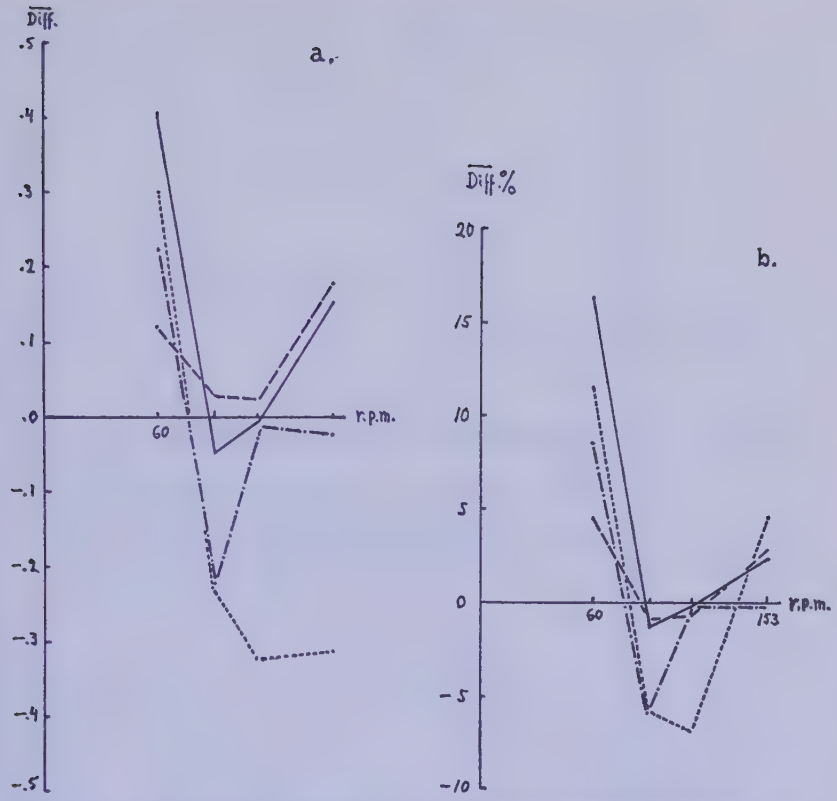


Diagram 9.3 Experiment XI, group matrix. Differences between column—row scales illustrating the effect of a stimulus appearing as standard or variable according to the model $q_{ij} = {}^{R}i,\ v/R'_{i.s}$.
———— = Silent, $column_s$—Silent, row_v
— — — — = Loaded, $column_s$—Silent, row_v
. . . . . = Silent, $column_s$—Loaded, row_v
—.—.—.— = Loaded, $column_s$—Loaded, row_v
a) Mean differences, b) mean differences in percent.

In Diagram 9.5 and 9.6 is shown the "pure" effect of auditive intermittent frequency. In Diagram 9.5 are given the difference curves for loaded $_{row,\ matrix\ 3}$–silent $_{row,\ matrix\ 1}$ and loaded $_{row,\ matrix\ 4}$–silent $_{row,\ matrix\ 2}$. Bot curves reflect differences between

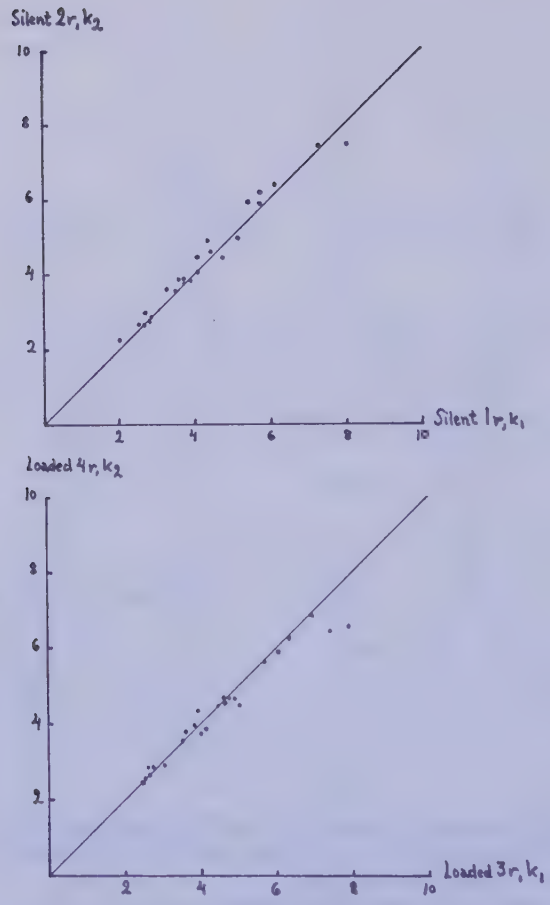


Diagram 9.4 Silent and loaded row scale values measured in different units.
k_1 = silent velocity standard
k_2 = loaded velocity standard

variable-scales. In the first case, silent velocities are used as standards and in the second case loaded velocities are used as standards.

In Diagram 9.6 difference curves between scales from the total matrix are given. The row differences are between variable scales

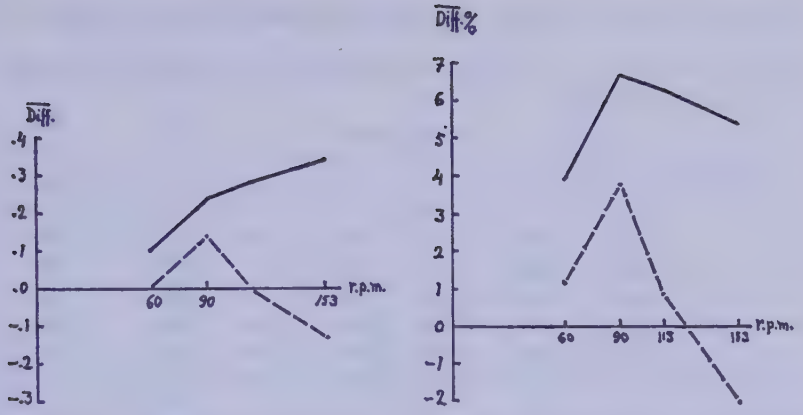


Diagram 9.5 Illustration of the "pure" sensory interaction effect. Manually computed scales.
———— = submatrix 3 loaded rows—submatrix 1 silent rows (variable scales, silent standard).
— — — — = submatrix 4 loaded rows—submatrix 2 silent dows (variable scales, silent standard).

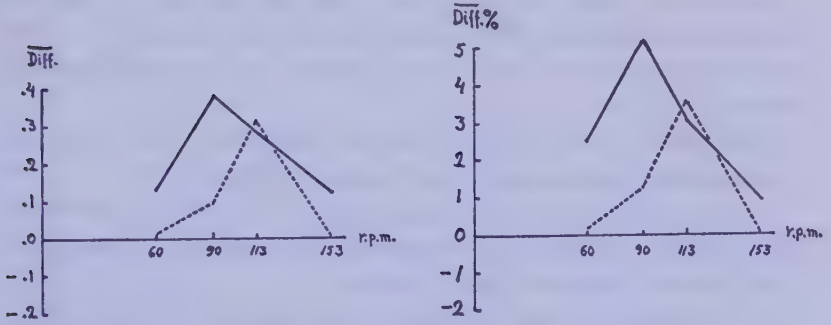


Diagram 9.6 "Pure" sensory interaction effect. Total matrix.
———— = loaded rows—silent rows (variable scales).
— — — — = loaded columns—silent columns (standard scales).

and the column differences between standard scales. All four difference curves appear similar. The relative size of the effect coincide with the ones found earlier (although those in chapters 6 and 8 do reflect the combined effect of standard/variable and

Table 9.2. Factor analysis of individual complete ratio matrices.

In the table are given the cumulative proportions of respective trace values for successive latent roots.

Latent root number	Subject number						Group
	1	2	3	4	5	6	
1	.994	.996	.989	.995	.992	.983	.996
2	.997	.998	.998	.998	.997	.994	.999
3	.999	.999	.998	.999	.999	.998	.999
4	.999	1.000	.999	1.000	1.000	.999	1.000
5	1.000	1.000	1.000	1.000	1.000	1.000	1.000

sensory interaction). Further the curves shown here builds on the highest four velocities of the six used previously (20, 36, 60, 90, 113 and 153 r.p.m.). It is worth noting that neither the combined effect curves (diagrams 9.1 and 9.2) nor the pure effect curves (diagrams 9.5 and 9.6) show the "dip" on the second smallest stimulus, found earlier. Instead, the curves reflect the same pattern as the one given by the common velocities in the experiments in chapters 6 and 8.

The results from the factor analysis of the individual response matrices and the group matrix are shown in Table 9.2.

As seen, in no individual response matrix was less than 98 % of the variation accounted for by the first latent root. All the matrices could thus be considered unidimensional.

In Diagram 9.7 are given the plots between the computed scales and the scales obtained by factor analysis. Agreement as to linearity is close.

In Diagram 9.8 are shown the relative difference curves between loaded - silent row scales (variable scales) and loaded - silent column scales (standard scales) from the factor analysis. For convenience these curves are computed from the group matrix. The effect of auditive intermittent frequency obtained in this way coincides with that obtained by conventional computation.

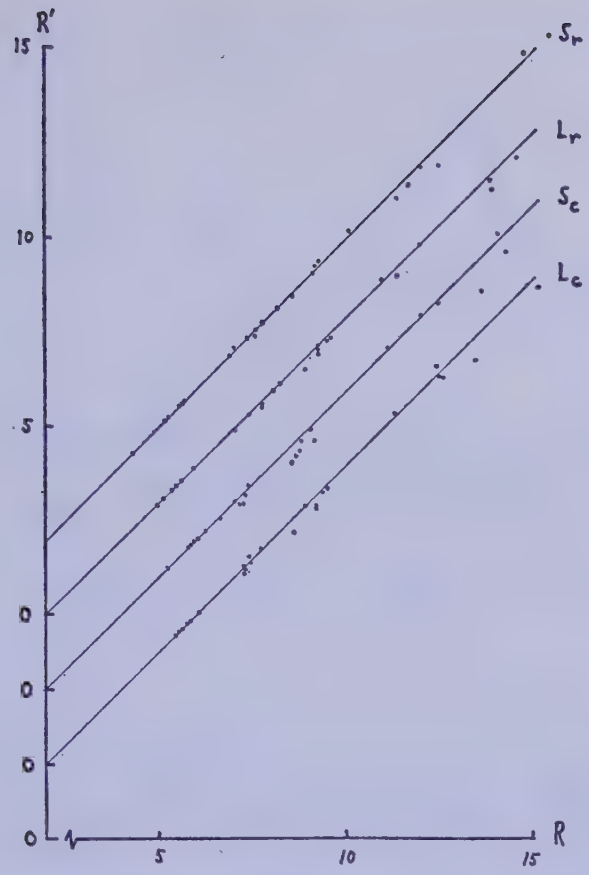


Diagram 9.7 Plots between manually computed scales (R) and scales from factor analysis (R').
Total matrix. S = silent, L = loaded, r = rows, c = columns.

Finally in Diagrams 9.9 and 9.10 are then given the plots between empirical ($\overline{q}_{emp}$) and computed ($\overline{q}_{comp}$) ratios for subject 1 and for the group matrix. Plots from the remaining five subjects gave similar results and are given in Table III.1 of Appendix III. As seen there is close agreement to the 45° slope and the matrices may be considered unidimensional and internally consistent.

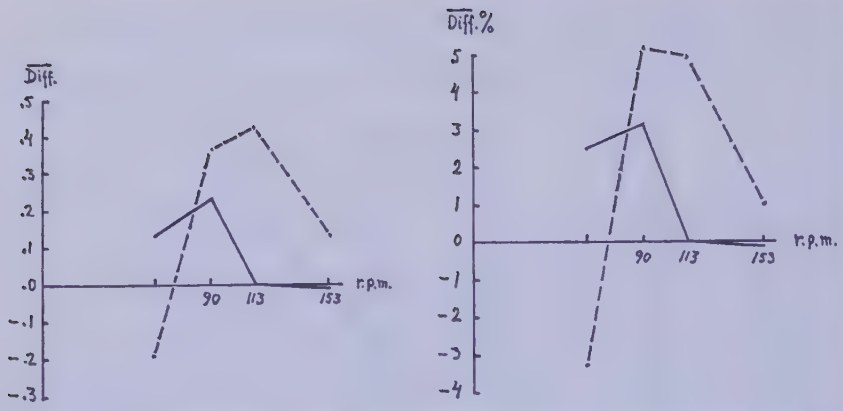


Diagram 9.8 Illustration of the "pure" sensory interaction effect. Scales from factor analysis, group matrix.
———— = loaded rows—silent rows (variable scales).
— — — — = loaded columns—silent columns (standard scales).

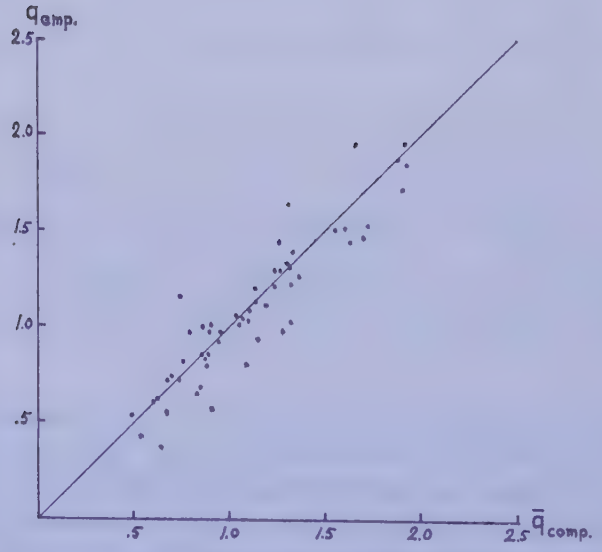


Diagram 9.9 Experiment XI, Subject 1. Arithmetic means of computed ratios ($\bar{q}_{comp.}$) plotted against empirical ratios ($q_{emp.}$).

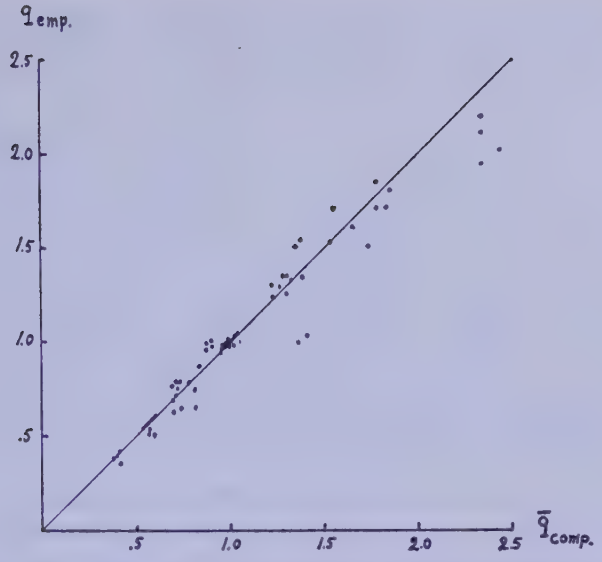


Diagram 9.10 Experiment XI, group matrix. Arithmetic means of computed ratios ($\bar{q}_{comp.}$) plotted against empirical ratios ($q_{emp.}$).

9.4 *Discussion and conclusions*

Seven problems were formulated to be answered by the present experiment. These will be discussed briefly in relation to the results presented above.

In this experiment the four highest velocities of the six used in previous experiments were used as stimuli. The relative effect of auditive intermittent frequency on these four common velocities is similar in all experiments. In the earlier experiments it was repeatedly suspected that the difference between loaded and silent scales may be an artifact (e.g. of the method used) and not an effect of sensory interaction. So far this suspicion has been negated by repeated results from ratio estimation using a) different stimuli sets, b) different standard stimuli sets and by similar findings from magnitude estimation. In this experiment it is shown that the earlier found loaded - silent difference curves do reflect a pooled effect of a differential subjective evaluation of a stimulus appearing as

standard and variable and auditive intermittent frequency. If this first effect is eliminated a striking similarity within the body of results remains. Whether the differences found depend on changes in the judgemental language used or if they also appear when a method free from response bias is used, remains to be investigated.

It was predicted that the effect of auditive intermittent frequency would be increased when the presentation time was decreased and fixed. The prediction was not confirmed. Analysis of the first and fourth judgement instance does not give any further information. The only thing that is found is that data are more stable over trials than in previous experiments. For this reason the analysis is not presented. (The complete response matrix yields four silent/silent and loaded/loaded judgement instances but *eight* silent/loaded (or reversed) judgement instances.) The increased stability of data may depend on a number of factors, such as the smaller number of velocities used, the shortened presentation time etc.. All subjects proved to be capable of carrying out the task, giving consistently ratios $\geqq 1.00$. In fact, no difference in consistency or dimensionality was found between this experiment, where the subjects explicity were instructed to give ratios $\geqq 1.00$. and the earlier experiments where they could only give ratios $\leqq 1.00$. This may be taken as indirect support for the soundness of the convention employed in the earlier experiments.

The effects of changes in the unit of measurement proved small. As earlier noted in Chapter 8 the higher scale values seem to be more affected than the rest. This can be taken as a weak indication that the original data model hitherto used is inadequate.

The data model is also proved inadequate by the similar difference curves between standard and variable scales shown in Diagram 9.3. The alternative data model, including the effect of standard/variable as well as the auditive intermittent frequency effect, proves better suited to describe the data. It also allows for a computation of the "pure" effect of sensory interaction. Unfortunately it is not possible to reanalyse the previous ratio estimation experiments and from these data get a comparable "pure" estimate of the sensory interaction.

The unidimensionality and the internal consistency of both

individual and group matrices are good. It is still possible that the test procedures employed here are insensitive to certain types of inconsistencies, e.g. that produced by changes in the unit of measurement.

This experiment shows that:

a) there is an effect of auditive intermittent frequency
b) this effect can be measured by ratio estimation
c) subject judge the same attribute in silent and loaded velocity.

It is still unclear whether the sensory interaction effect found should be regarded as a change in the subjects judgemental language or if it is to be considered as a change in their perception of velocity—in the sense that it would also be found using a method in which changes in the judgemental language is impossible. This last question will be considered in the next chapter.

Four experiments on silent and loaded velocity, silent and loaded time and the Müller-Lyer illusion with paired comparisons and ratio scaling

10.1 *Introduction*

Previous experiments have shown that a loaded velocity in general is overestimated as compared to a silent velocity when the two types of velocities are scaled with the generalized method of ratio estimation or a variant of the method of magnitude estimation. Is this overestimation to be regarded as a change in the subject's judgemental language (as a response-bias), or as a basic change unaffected by the judgemental language? This latter change is referred to as a change in the perception of the subjects—perception being defined as a hypothetical process inferred by the observed ordinal invariance of responses to a constant stimulus situation.

The experiment by Johansson (op. cit. chapter 4), using the method of reproduction, taken together with my own experiments, indicates that auxiliary auditive stimulation affects perception rather than the use of the judgemental language. The theory of Sokolov (op. cit. chapter 4) localizes the mechanism to the orienting reflex over which the auxiliary stimulation affects perception, predicting that the effect will be greater at the outset and gradually disappear when stimuation is repeated. The prediction agrees in part with the change of effect over judgement instances observed in many experiments. Sokolov predicts a gradual disappearance of the effect as trials are repeated. My experiments suggest that the effect first decreases and then reappears, as measured over 4 trials.

In Johansson's discussion, velocity is described as being composed of a spatial and a temporal component. (It is a bit unclear whether Johansson refers to subjective or physical parameters or both. Here I assume that subjective parameters are discussed.) Johansson tentatively explains the observed overestimation by saying "that the timestream flowed more slowly" in the stimulus-pattern containing a lower auditive intermittent frequency. The time component of the velocity is thus considered more labile and the resultant velocity judged is perceived differently when an intermittent frequency affects this time component. The experiments by Frankenhauser (op. cit. chapter 4) show that estimates of subjective time also are affected in the same direction by auditive intermittent frequencies.

Johansson only compared a pair of differently loaded velocities and thus did not encounter the differential effect of intermittent frequency on different velocities found in the present study. Frankenhauser studied subjective time and found an approximately constant effect of intermittent frequency over a range of subjective times.

In the first two experiments of this chapter the effect of auditive intermittent frequency on silent and loaded velocity and silent and loaded time will be studied through a modified version of paired comparisons. The specific problems will be stated in the next section.

Another important question is how the size of the effects found should be rated. Because of conditionality within the data body, significance testing is ruled out. Another way of handling this is to compare the size of the effects found with that of a more established phenomenon measured with the same method. For this purpose were chosen distance estimates—unaffected and affected by the Müller-Lyer illusion. The last two experiments in this chapter demonstrate the use of generalized ratio estimation and paired comparisons on a Müller-Lyer pattern. Here the Müller-Lyer illusion is regarded as an example of unimodal sensory interaction and comparisons are made between this effect and the bimodal effect of auditive intermittent frequency on velocity.

The specific problems for these experiments are stated in the next section.

10.2 *Problems*

The specific problems to be studied in Experiment XII, paired comparisons of silent and loaded velocities, are:

1. Can the effects earlier found by Johansson and myself, using the method of reproduction, generalized ratio estimation and magnitude estimation, also be measured by paired comparisons?
2. Is the same relative difference curve found earlier between loaded and silent velocities, also found with paired comparisons?
3. Is a change of effect over judgement instances found with paired comparisons? The previous experiments with direct scaling methods indicate (cautiously) that the effect should be greatest at the first instance, decrease over the second and third and reappear at the fourth judgement instance.
4. How does the effect change (if it does) when more than four judgement instances are studied? Sokolov (ibid. chapter 4) predicts that the effect should disappear.

In Experiment XIII, paired comparisons of silent and loaded time, the following problems are studied:

1. Can the same effects of auditive intermittent frequency found on velocity also be found on time measured with paired comparisons?
2. Can both past and present time estimates be used?
3. Is there a differential effect of intermittent frequency on different time intervals?
4. Does the effect change with the number of judgement instances?

Experiment XIV is a demonstration of how the Müller-Lyer illusion could be measured with generalized ratio estimation. The specific questions to be illustrated are:

1. Can the illusion be measured by generalized ratio estimation?
2. Is the illusion constant over the range studied as predicted from classical experimentation?

3. How does the relative size of the illusion compare to:
   a) the size of the illusion measured by classical psychophysical method?
   b) the relative size of the effect of auditive intermittent frequency on velocity?

The last experiment in this chapter, Experiment XV, is a demonstration of how the method of paired comparisons functions on the Müller-Lyer illusion. The specific issues to be studied and illustrated are:

1. Can the Müller-Lyer illusion be measured by paired comparisons?
2. If so, how does the relative size compare to that found with generalized ratio estimation?
3. How does the illusion change with training or repetition of judgement instances? (A series of experiments, e.g. Köhler and Fishbach (1950 a and b) have shown that the effect does disappear with training.)
4. How does such a change compare with that found in previous experiments on silent and loaded velocity and in Experiment XII?
5. Is such a change over judgement instances affected by intentional reinforcement during the training period or not?

10.3 *Experiment XII, velocity*

10.3.1 *Procedure*

Experiment XII was carried out according to the following plan:

Twenty velocities (20, 25, 36, 45, 55, 60, 70, 82, 90, 97, 105, 113, 126, 135, 145, 153, 170, 180, 189 and 200 r.p.m.) were selected. The selection was made according to the following principles:

a) All six previously used velocities should be in the set.
b) The range of velocities should be as large as the apparatus allowed.
c) The spacing of velocities within the set should be uneven in order to counteract the subjects' possible tendency to systematize their responses.

The velocities thus selected were to appear in pairs of equal velocities, one silent and one loaded (12 c/sec., 800 cps, 82,5 db). The pairs of velocities were arranged in a 20 × 20 latin square (each cell containing a pair) where rows and columns were randomized.

Twenty subjects (12 female, 8 male, age range 20–24 years) were presented one row of the twice permuted latin square and asked to indicate which velocity in each pair was the faster.

The same apparatus was used as in previous experiments; see Appendix I. External conditions were as earlier described.

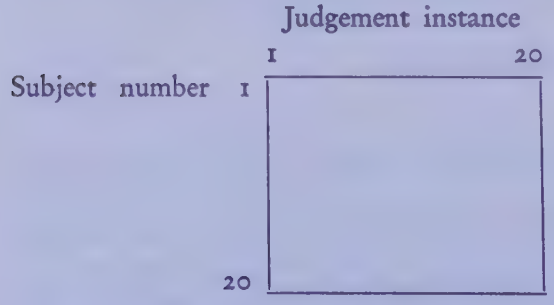
Each stimulus was presented for 2 seconds,

silent	loaded
2 seconds	2 seconds

the interstimulus internal being practically zero. Position and order within sequence were randomized.

10.3.2 *Results*

Raw data appear in the form of a 20 × 20 matrix containing a plus in the cells where loaded velocity is judged fastest, and a minus in the cells where silent velocity is judged fastest.



By summing the number of pluses in each column of the matrix, an overall estimate is obtained of the direction of the sensory interaction over all 20 stimuli-pairs at each judgement instance. If there is no effect, the proportion of pluses should lie around 50 %; but if the prediction from earlier experiments is verified,

Table 10.1. Experiment XII.

Paired comparisons of silent velocity and loaded velocity. The number of times loaded celocity or silent velocity is judged faster and %-age loaded velocity comparisons judged to be faster.

	Judgement instance									
	1	2	3	4	5	6	7	8	9	10
Loaded velocity judged fastest	15	8	7	11	11	8	11	12	16	12
Silent velocity judged fastest	5	12	13	9	9	12	9	8	4	8
% loaded velocity comparisons judged to be faster	75	40	35	55	55	40	55	60	80	60

	Judgement instance									
	11	12	13	14	15	16	17	18	19	20
Loaded velocity judged faster	14	10	13	11	13	8	11	11	11	15
Silent velocity judged faster	6	10	7	9	7	12	9	9	9	5
% loaded velocity comparisons judged to be faster	70	50	65	55	65	40	55	55	55	75

the proportion of pluses should start well above 50 % and decrease and increase over the first four judgement instances.

This analysis is presented in Table 10.1 and Diagram 10.1.

As seen these results agree with the previous body of results from ratio estimation and magnitude estimation.

10.3.3 *Comments*

The effect of auditive sensory interaction could be measured with paired comparisons. This indicates that the effect may be regarded as a change in the perception of subjects rather than as a response-bias. The relative difference curves found agree fairly well with the ones found earlier.

The change of the effect over judgement instances for the first four estimates is also in accordance with prediction. The Sokolov prediction is thus not verified. At later instances however, the effect oscillates in a cyclical manner. It is impossible to judge from

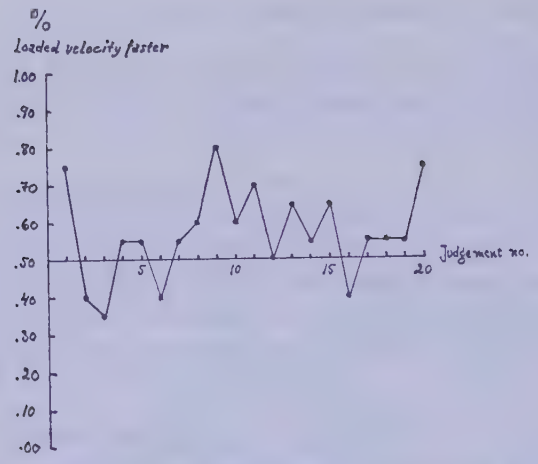


Diagram 10.1 Experiment XII. Percentage loaded velocity is judged faster than silent velocity.

this experiment whether these cycles reflect a true change. The mean effect over 20 judgement instances is 57 % and 15 out of 20 proportions lay above 50 %.

10.4 *Experiment XIII, time*

10.4.1 *Procedure*

In Experiment XIII paired comparisons of silent and loaded time were made.

Twenty times (5, 6, 7, 9, 10, 12, 13, 15, 16, 17, 19, 20, 21, 22, 24, 26, 28, 29 and 30 seconds) were selected, the spacing being uneven to counteract any tendency on the part of the subject to fit their responses to an assumed set of stimuli.

The times appeared in pairs of equal length, one silent and one loaded (12 c/sec., 800 cps, 825 db). The pairs of stimuli-times were arranged in a 20 × 20 latin square with a pair in each cell. The rows and columns of the square were permutated. Twenty subjects were each presented with one row of the matrix.

In one, not fulfilled version past time comparisons were made. Here two times were presented with a brief interval in between,

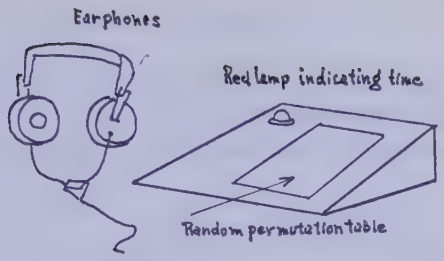


Figure 10.1 Experimental setupused in Experiments s. XIII a and XIII.

and the subject was instructed to indicate which time was longer. This is called Experiment XIII a. 15 subjects were used (7 female, 8 male, age range 20–26 years). In another version present time comparisons were made. This is called Experiment XIII. 20 subjects were used (16 female, 4 male, age range 20–24 years). The experimental setup for Experiment XIII a and Experiment XIII is schematically given in Figure 10.1.

The subject, wearing a set of earphones (giving auditive intermittent frequency) was seated at a comfortable reading distance from a small lectern, on which a red lamp indicated the time intervals (the loaded ones were heard as well). The subject was instructed to read aloud from the permutation table at the rate of one number per second when the red light was on.

In Experiment XIII a (Past time.) he indicated verbally which stimulus-interval was longer after a pair had been presented.

In Experiment XIII (Present time.) he marked with a pencil the number just read when the lamp went out and continued to read and mark off numbers each time the lamp was on. In Experiment XIII the subject was thus not asked to give any direct comparisons. Instead the comparisons were calculated from each subject's response sheet.

In both versions the sequence of silent/loaded times was randomized. The interstimulus-pair interval was marked longer than the interval within pairs.

Table 10.2.

Subjective impressions after Experiment XIII a on the question: "Were the times presented objectively equal, unequal or some equal, some unequal?" 15 subjects were questioned:

All equal	All unequal	Some equal, some unequal	Extreme unequal	Short equal	Long equal
4	2	4	1	1	3

10.4.2 *Results*

Experiment XIII a was terminated before it was finished (after 15 subjects) on account of the universal tendency to judge according to the time-order error, i.e. the last time presented was judged to be longer irrespective of whether it was silent or loaded.

The participating subjects were interviewed and asked whether they thought the silent and loaded times presented were in fact unequal, eual or some equal and some unequal. These subjective impressions are given in Table 10.2.

As seen only 4 subjects out of 15 had a suspicion that there was an objective equality within pairs (irrespective how they actually judged).

Experiment XIII differed from Experiment XIII a in that the subjects were not asked to compare the times within a pair. Instead they read and marked off numbers at the pace of one number per second. Each subject thus gave 2×20 present time estimates. Consecutive pairs could then be analyzed, and a matrix of paired comparisons was computed for the 20 subjects' estimates of $2 \times 20 \times 20$ silent and loaded times. Each pair of silent and loaded times was coded as equal (0), loaded shorter (−) and silent shorter (+). This analysis is given in Table 10.3 and Diagram 10.2.

As seen from Table 10.3 and Diagram 10.2 these results agree fairly well with those from Experiment XII. There it was found that loaded velocity was judged faster as compared to a silent

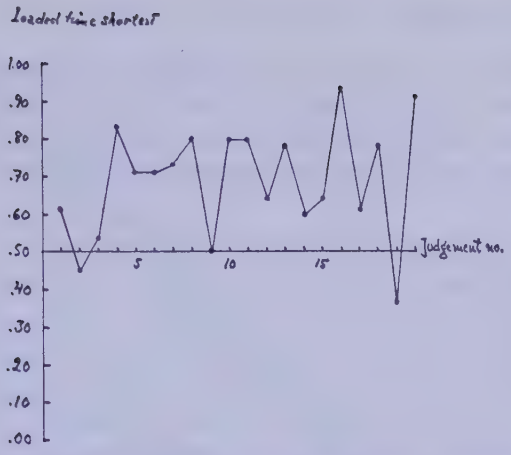


Diagram 10.2 Experiment XIII. Loaded time judged as shorter than silent time in percent of 20 comparisons minus the number of times silent and loaded time are judged equal.

Table 10.3. Experiment XIII.

Calculated pair comparisons of present time estimates.

Judgement instance	1	2	3	4	5	6	7	8	9	10
Both times equal	7	9	7	8	6	6	5	5	4	5
Loaded time shorter	8	5	7	10	10	10	11	12	8	12
Silent time shorter	5	6	6	2	4	4	4	3	8	3
Loaded < silent in % of (±).	61.5	45.5	53.8	83.3	71.5	71.5	73.4	80.0	50.0	80.0

Judgement instance	11	12	13	14	15	16	17	18	19	20
Both times equal	10	6	6	5	6	6	7	6	9	8
Loaded time shorter	6	9	11	9	9	13	8	11	4	11
Silent time shorter	4	5	3	6	5	1	5	3	7	1
Loaded < silent in % of (±).	80.0	64.4	78.5	60.0	64.4	92.85	61.5	78.5	36.5	91.7

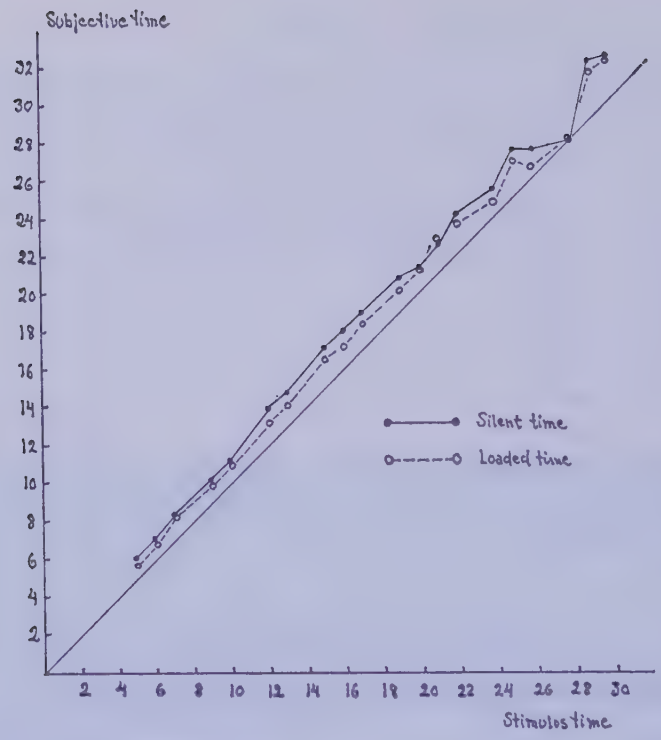


Diagram 10.3 Experiment XIII.
Subjective silent and loaded time plotted against stimulus time.

velocity. That implies that the loaded subjective time component is judged shorter than the corresponding silent time component, i.e. the loaded subjective second goes slower. It further should be noticed that the decrease-increase in sensory interaction effect over the first four judgement instances is similar in both experiments.

In Experiment XIII another analysis is possible. As the subjects gave separate present time estimates of silent and loaded times in each pair, these estimates may be averaged for each silent and loaded time and these means can then be plotted against the actual times presented. This analysis is given in Table 10.4 and Diagram 10.3.

Table 10.4. Experiment XIII.

Stimulus times and arithmetic means of silent and loaded present time estimates for the group of 20 subjects. All times given in seconds. Mean difference between silent and loaded times are also given as %-ages of the corresponding silent time estimate.

Stimulus time	5	6	7	9	10	12	13	15	16	17
Silent time est.	6.00	7.00	8.35	10.05	11.10	13.85	14.70	17.05	17.90	18.80
Loaded time est.	5.60	6.70	8.20	9.80	10.80	13.25	14.00	16.45	17.15	18.30
Diff. L-S	—.40	—.30	—.15	—.25	—.30	—.65	—.70	—.60	—.75	—.50
Diff. % L-S	—6.67	—4.28	—1.80	—2.49	—2.70	—4.69	—4.76	—3.52	—4.19	—2.66

Stimulus time	19	20	21	22	24	25	26	28	29	30
Silent time est.	20.70	21.20	22.55	24.25	25.40	27.55	27.55	27.90	32.10	32.40
Loaded time est.	20.15	21.20	22.80	23.45	24.75	26.85	26.50	27.45	31.55	32.20
Diff. L-S	—.55	—.10	.25	.20	—.65	—.70	—.105	.05	—.55	—.20
Diff. % L-S	—2.66	—.47	1.11	.82	—2.56	—2.54	—3.81	.18	—1.71	—.62

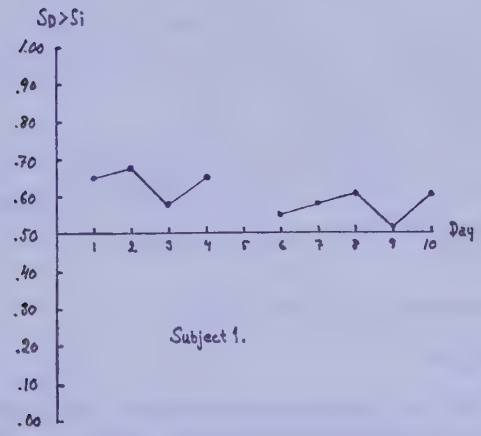


Diagram 10.4 Experiment XV. Subject 1, non-reinforced. The proportion of S_d judged as longer than S_i.

10.4.3 *Comments*

Three observations could be made from Table 10.4 and Diagram 10.3: The first is the close resemblance in results between this experiment and earlier findings by Frankenhauser. The second is that both silent and loaded present time estimates are systematically overestimated as compared to objective time, and that loaded subjective time is less overestimated than silent subjective time. The systematic overestimation of both silent and loaded times may be explained as an anchor effect of the auditive intermittent frequency of 12 c/sec. This effect is discussed by e.g. Behar & Bevan (1961). My results so interpreted are also in line with findings of Goldstone, Boardman and Lhamon (1959) who found that auditive intervals are perceived ca. 20 % longer than objectively equal silent intervals, i.e. the subjective loaded second is perceived as shorter. A third observation is that subjective time appears to be affected in one direction only by an auditive intermittent frequency irrespective of the length of the stimulus time. With velocity it has been repeatedly found that the direction of the effect changes for different velocities. A tentative explanation may be that subjects in the velocity experiments make relative judgements (although the same attributes are judged) of the seen and heard stimuli while in the time experiment they do not. The change of direction of the effect may occur if e.g. one seen velocity is perceived as faster than the intermittent frequency and another seen velocity is perceived as slower, the intermittent frequency in both cases being used as a reference velocity.

Diagram 10.2 shows that the effect of intermittent frequency on subjective time is not—as Sokolov predicts—extinguished when stimulation is repeated.

10.5 *Experiment XIV, Müller-Lyer*

10.5.1 *Procedure*

Experiment XIV is a demonstration of how the generalized ratio estimation method measures a well known phenomenon. viz. the Müller-Lyer illusion.

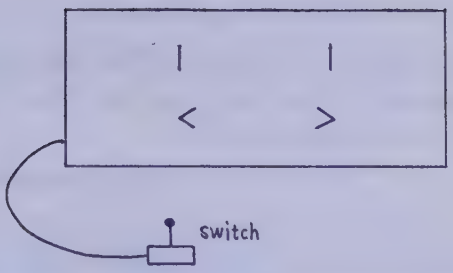


Figure 10.2 Apparatus used in Experiment XIV and XV. For an explanation see the text.

The apparatus used is shown in Figure 10.2.

The subject was seated ca. 1.5 meters from the apparatus with the switch in one hand. The switch was normally in a neutral position and both distances on the screen were extinguished. If the subject moved the switch to the right, the top distance was shown; if he moved the switch to the left, the Müller-Lyer distance below was shown. The experimental room was kept in darkness and the subject thus only saw the distances produced on the screen.

One female subject (age 25) served as subject.

She was instructed to estimate the ratio between the pure distance (distance) and the distance loaded with the arrow head and tail (illusion). Distance was used as standards, and she was instructed to give ratio $\leqq 1.00$. The whole matrix, including diagonal cells, was filled with empirical ratios. Six ratios were given in each cell. She was allowed to switch between distance and illusion as many times as she wanted.

Five distances were used: 10, 15, 25, 35 and 40 cm.

10.5.2 *Results*

The two scales were computed as previously described and are given in Table 10.5 together with the difference between the two scales.

Table 10.5. Experiment XIV.

Scale values of distance and distance with the Müller-Lyer illusion, the difference between these scales andt his difference being given in percent of the distance scale.

	Stimulus length in cm.				
	10	15	25	35	40
Distance scale	2.60	4.10	6.27	8.76	10.21
Illusion scale	2.30	3.52	5.95	8.74	9.88
Diff.	.30	.58	.32	.02	.33
Diff. %	11.54	14.15	5.10	0.23	3.23

As seen from Table 10.5 the two scales differ from each other in the manner predicted from classical experimentation. The mean size of the illusion compares fairly well with the size of the effect of auditive intermittent frequency found in the experiments on velocity. It must be remembered however that the difference measure given here is (as shown in chapter 8) a pooled effect of the illusion and the differential subjective evaluation of standard and variable.

A curious finding that could not be resolved here is the variation of the size of the effect over the range studied. According to classical experimentation (see e.g. Guilford 1936), the relative illusion should be constant, and follow the Weber law. Whether the variation found here is random or systematic could not be determined.

10.6 *Experiment XV*

10.6.1 *Introductory remarks*

The problems for Experiment XV have earlier been stated in Section 10.2. As the Müller-Lyer illusion is generally strong and could only be changed after a relatively large number of repetitions, the experiment was planned to stretch over several days. Several different questions are raised that could not be answered

by our set of data. Therefore Experiment XV comprises a number of subexperiments performed on the same subjects over a certain period of time.

10.6.2 *Procedure of Experiment XV*

The same apparatus as was described in Section 10.5.1 and Figure 10.2 was used with the difference that the experimenter handled the apparatus.

Two female subjects (age 18 and 26) participated. Neither of them had studied psychology or served as subjects in an experiment before.

The subjects were instructed to make paired comparisons of distances (S_d) and distance loaded with arrow head and tail (S_i).

As stimuli were used

1) 20 pairs where $S_d = S_i$, namely

10, 13, 15, 17, 19, 20, 21, 23, 24, 26, 27, 29, 30, 32, 33, 35, 37, 40, 43 and 45 cm.

2) 10 pairs where $S_d \neq S_i$, namely

$S_d =$ |—| 8.5, 16, 16, 20.5, 21, 26, 29, 33, 34.5, 42.5

$S_i =$ ⟨ ⟩ 9, 15, 17, 22, 20, 25, 30, 32, 35, 40

The experiment was run every day for 10 days with a break on day 5—a Sunday.

The set of 20 $S_d = S_i$ were presented in a new permutation each time. The set of 10 $S_d \neq S_i$ also appeared in a new permutation each time but had a constant place within the sequence of 20 $S_d = S_i$.

Each subject received $2 \times [(20\ S_d = S_i) + (10\ S_d \neq S_i)]$ at the same hour on each of 10 consecutive days (excluding day 5).

Subject 1 was tested each day at 13.30—14.15.

Subject 2 was tested each day at 18.00—18.45.

Subject 1 went through each session without comments from the experimenter. Subject 2 was reinforced for each correct answer with 50 öre on the 10 $S_d \neq S_i$. Subject 2 was not informed that a stimuli pair belonged to the $S_d \neq S_i$ set until she had answered.

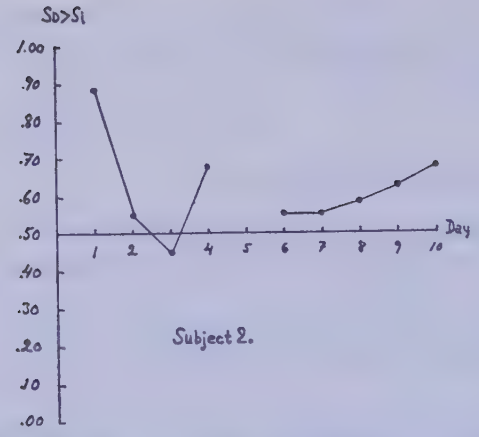


Diagram 10.5 Experiment XV. Subject 2, reinforced. The proportion of S_d judged as longer than S_i.

One week after the experiment was terminated both subjects went through a method of limits measurement of the illusion using the same apparatus.

10.6.3 *Results*

On the $S_d = S_i$ test for each subject, the proportion of S_d's judged as longer than S_i's was calculated. These proportions are given in Table 10.6. The corresponding curves are given in Diagram 10.4 for subject 1 (non-reinforced) and in Diagram 10.5 for subject 2 (reinforced).

In Table 10.7 are given the proportions of correct judgements in the $S_d \neq S_i$ set and in the following two Diagrams 10.6 and 10.7 are given the curves for subjects 1 and 2.

For both subjects a slight repetition effect is found. Reinforcement seems to have a negligible effect. The development over the first four judgement instances are similar when results from velocity, subjective time and distance with the Müller-Lyer illusion are compared. This might naturally be a coincidence. The later development of the response curves is also hard to interpret. A tenta-

Table 10.6. Experiment XV.

Proportion of S_d judged as longer than S_i at each session (20 $S_d = S_i$) and each day (40 $S_d = S_i$).

Day	1		2		3		4		5	6		7		8		9		10	
Session	1	2	3	4	5	6	7	8	x	9	10	11	12	13	14	15	16	17	18
Subject 1 (non reinforced)	.60	.70	.70	.65	.65	.50	.80	.50		.60	.50	.65	.50	.60	.60	.50	.55	.60	.60
	.650		.675		.575		.650			.550		.575		.600		.525		.600	
Subject 2 (reinforced)	.95	.80	.65	.45	.45	.45	.65	.70		.65	.45	.55	.55	.55	.60	.70	.55	.70	.65
	.875		.550		.450		.675			.550		.550		.575		.625		.675	

Table 10.7.

The proportion of correct judgements on $S_d \neq S_i$ each session (10 $S_d \neq S_i$) and each day (20 $S_d \neq S_i$).
(S_d = distance, S_i = distance with Müller-Lyer illusion.)

Day	1		2		3		4		5	6		7		8		9		10	
Session	1	2	3	4	5	6	7	8	x	9	10	11	12	13	14	15	16	17	18
Subject 1 (non reinforced)	.70	.50	.90	.70	.90	.80	.80	.100		.50	.70	.80	.80	.60	.70	.90	.100	.70	.90
	.60		.80		.85		.90			.60		.80		.65		.95		.80	
Subject 2 (reinforced)	.70	.70	.60	.80	.70	1.00	.70	.80		.70	1.00	.70	.70	.90	.90	.90	.80	.90	.70
	.70		.70		.85		.75			.95		.70		.90		.85		.80	

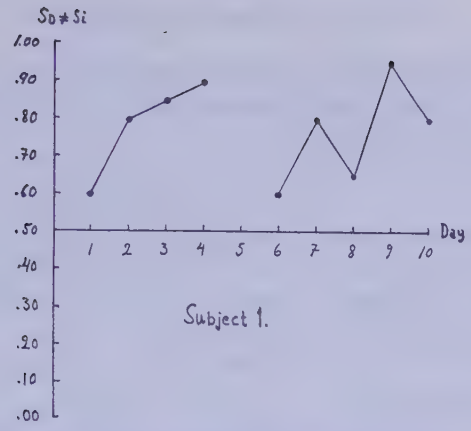


Diagram 10.6 Experiment XV. Subject 1, non-reinforced. The proportion of correct judgements on the $S_d \neq S_i$.

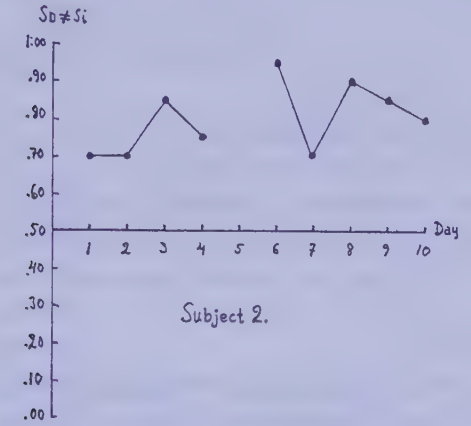


Diagram 10.7 Experiment XV. Subject 2, reinforced. The proportion of correct judgements on the $S_d \neq S_i$.

tive guess is that a decrease in motivation may account for some of the variation.

In Experiment XV a further measurement was made. One week after the ten day sequence both subjects went through a method

Table 10.8. Experiment XV.

Strength of the Müller-Lyer illusion measured 1 week after a 10 day sequence of paired comparisons with the method of limits. $S_a - S_i$ in centimeters ($n = 8$).

	Standard distance				
	10	20	26	33	45
Subject 1 (non reinforced)	0.07	—0.25	0.41	—0.09	—0.56
Subject 2 (reinforced)	0.10	—0.18	—0.40	—0.23	—0.58
Subject 3 (control)	—1.23	—1.35	—1.19	—1.04	—1.51

of limits measurement of the strength of the Müller-Lyer illusion. The prediction is that the illusion should be smaller than usually found, or even overcorrected, i.e. negative. The results from this test are given in Table 10.8.

As seen subject 1 and subject 2 both show a considerably smaller degree of the illusion than control subject 3.

This does not contradict the guess that changes in motivation may have influenced the results of the paired comparisons.

10.6.4 *Comments*

Experiment XIV and Experiment XV indicate that as far as data go there are marked similarities between a unimodal sensory interaction situation and the bimodal situations earlier studied. The Müller-Lyer illusion proves to be measurable by the method of generalized ratio estimation as well as by the response bias-free method of paired comparisons. The effect of repetition describes a cyclical development and the illusion is markedly diminished by repetition. Both the illusion and the repetition effect appear not to be influenced by reinforcement.

Experiment XII (paired comparisons of silent and loaded velocity) showed together with earlier experiments that the effect of auditive intermittent frequency is not an artifact of the method of measurement or the result of changes in the subjects' judgemental language. The effect is found with the method of reproduction (Johansson ibid.), ratio estimation, magnitude estimation and paired comparisons, and the combined body of data from these experiments show a considerable consistency. It should be remembered (as mentioned in chapter 5) that so far five independent experimenters have collected the data.

The effect also seems to change in a rather consistent manner over the first four judgement instances. The effect is initially great, diminishes or is overcorrected and then reappears at the fourth instance. If, however, the number of repetitions is increased up to 20, as is the case in Experiment XII, the effect does not appear to stabilize or disappear. Instead the fluctuations continue. This finding lowers the relevance of the systematic change observed over the first four judgement instances. A decrease in motivation may explain the results (as was guessed in Experiment XV) although it is rather improbable since a session in Experiment XII only took about 20 minutes. Other possibilities are that the effect changes cyclically or that the variations are random. The first alternative lacks convincing backing from other experimentation on sensory interaction, and the second alternative should be seen in relation to the magnitude of the fluctuation. The issue could not be adequately resolved.

Experiment XIII (paired comparisons of subjective time) yields similar results and the comments above apply to this experiment as well. This experiment further shows that the effect of auditive intermittent frequency on subjective time, as contrasted with the same effect on velocity, only goes in one direction. It is possible that judgement of silent and loaded velocity is relative, while comparable time judgement is absolute, i.e. the intermittent frequency is not experienced as being separate from the stimulus time proper.

The experiments on the Müller-Lyer illusion (XIV and XV) serve as demonstrations partly of the application of a method of measurement on a well-investigated phenomenon, partly as a reference basis when estimating the size of the sensory interaction earlier studied, and the degree of change over judgement instances.

When measured with identical methods the effect of auditive intermittent frequency is of the same magnitude as the Müller-Lyer illusion. This is a rather astonishing result, as sensory interaction in general gives small and labile effects while the Müller-Lyer illusion is considered strong. The comparison is however far from perfect. Only one subject is tested on the Müller-Lyer illusion. The illusion pattern used is not the conventional one. (Here the reference distance and the distance with illusion were never presented simultaneously.) The same argument also holds for the observed changes of the illusion over judgement instances. The changes observed are about the same size as those found earlier for velocity and subjective time and no marked stabilization is noticeable. The method of limits measurement after the series of paired comparisons shows that the illusion is diminished or reversed. Also, this comparison between the two types of sensory interaction is imperfect. And most important, the repetition of the Müller-Lyer illusion is spread out over 10 days as compared to the 20 minutes sessions for velocity and time.

However, there remains a certain similarity in data and in changes within data.

Chapter 11

Similarity matchings of intermittent frequency and velocity and generalized ratio scaling of silent and loaded velocity

11.1 *Introduction*

The four experiments to be reported in this chapter are of two types. Two of them, Experiment XVI and Experiment XVII, are similarity matchings of auditive or visual intermittent frequency and velocity. The other two, Experiment XVIII and Experiment XIX, are generalized ratio scaling of silent velocity and auditively or visually loaded velocity.

The similarity matching experiments are done in order to study subjects' ability to match, by the method of reproduction, visual speed and auditive or visual intermittent frequency. These results will be compared to the findings from Chapter 8 where it was shown that subjects could give consistent ratio estimates of visual speed and auditive intermittent frequency.

If subjects can carry out similarity matchings as well, these data can be used to equate the subjective scales of silent and loaded velocity and auditive intermittent frequency.

The similarity matching experiments are done with auditive and visual intermittent frequency. This is done to get information on how the same frequency is perceived when it is given auditively and visually.

The two ratio scaling experiments are carried out to study whether the sensory interaction effect varies when the auxiliary stimulation is given intermodally and intramodally. Some of the experiments reviewed in Chapter 4 (Behar & Bevan 1961) suggest that the effect of a visually given "loading" should be greater than an auditively given one. The same conclusions may be drawn from

Johansson's results (op. cit.). In his discussion he says however that it is the temporal component that determines the experienced velocity when the spatial and the temporal components are in conflict. This suggests that, if an intermittent frequency is perceived in the same manner irrespective of whether it is given auditively or visually, the sensory interaction effect will be the same. A comparison of the four experiments to be reported here may give some information on this point.

11.2 *Two similarity matching experiments*

11.2.1 *Problems*

Experiment XVI and Experiment XVII were done in order to obtain information on the following points:

1. Can subjects make consistent similarity matchings between:
   a) auditive intermittent frequency and silent velocity;
   b) visual intermittent frequency and silent velocity?
2. Are the auditive and the visual intermittent frequencies matched to the same velocity when equal frequencies are compared?
3. How do the auditive intermittent frequency and velocity matchings compare with those found earlier in Chapter 8 by ratio estimation?

11.2.2 *Apparatus and subjects*

The apparatus used in these experiments is described in detail in Appendix I. The parts seen by the subjects are similar to those reported in earlier experiments.

The auditive intermittent frequency is presented by means of earphones. The visual intermittent frequency is presented by means of a photostrobotac lamp attached to the outside lower side of the semitransparent screen facing the subject. The subject could vary the seen velocity by turning a crank with his right hand. The velocity could be varied continuously within four ranges: 0–75, 0–250, 0–750 and 0–2500 r.p.m.

Both experiments were carried out in a semidark room.

25 subjects (23 of whom were students of psychology, and 2 high school pupils) participated in the experiments.

	Female	Male		Age range	Mdn
Pre-trial	2	3	5	18—29	24
Experiment XVI	6	4	10	18—29	23.5
Experiment XVII	7	5	10	22—26	23

Each subject participated in one experiment only.

11.2.3 *Procedure*

A variation of the method of reproduction was used. The task was to match a variable visual velocity to a number of auditive or visual intermittent frequencies. The velocity and the intermittent frequency were presented simultaneously. The subject was free to work at his own pace and was allowed to change the velocity range initially used and to "bracket" his final matching. The variable velocity was initially set high or low, i.e. descending and ascending series were employed.

To determine a suitable velocity range as well as high and low starting velocities, five subjects were studied. For these five subjects the velocity range between 0—750 r.p.m. proved sufficient. Starting velocities of about 20 p.p.m. and 700 r.p.m. were selected as suitable.

Six intermittent frequencies were used:

2, 4, 6, 8, 10 and 12 tones or lights per second (tps or lps) or 120, 240, 260, 480, 600 and 720 tones or lights per minute (tpm or lpm).

The tone pulses were of the same duration as the silent intervals (see Appendix I). The light pulses all had the same duration (ca. 1/10,000 sec.). The silent intervals thus varied in duration depending on the frequency.

The intermittent frequency was presented simultaneously with the velocity.

At each of the 6 intermittent frequencies 4 matchings were done

by each subject, 2 descending and 2 ascending. The number of matchings/subject was thus 24. The order of presentation was randomized. The presentation time/matching was unstandardized.

11.2.3 *Results*

Arithmetic means and standard deviations are calculated separately for each subject's matchings on each intermittent frequency for the ascending and descending series separately.

For Experiment XVI, auditive intermittent frequency, the means are given in Table 11.1 and the standard deviations in Table 11.2. The corresponding values for Experiment XVII, visual intermittent frequency, are given in Table 11.3 and Table 11.4. As seen from the tables there are great interindividual variations. The standard deviations are high. Within each of Table 11.1 and Table 11.3 the matched velocities tend to increase as the intermittent frequency is increased. Further it is seen that there is a marked difference between ascending and descending series in both experiments. The visual intermittent frequencies yield higher velocity matchings than the corresponding auditive intermittent frequencies.

All subjects found the tasks natural and easy to carry out.

In addition, interindividual means and standard deviations are computed by a method suggested by Eisler (1962). The four matchings at each intermittent frequency are multiplied by a factor making the arithmetic means of the four values equal to 1. On these transformed values the variance is computed separately for each individual and intermittent frequency. The pooled variance is computed over individuals. The square root of the pooled variance is then multiplied by the corresponding stimulus magnitude and the interindividual standard deviation is arrived at. The plot of these interindividual standard deviations against the matched velocities are given in Diagram 11.1 for Experiment XVI and in Diagram 11.2 for Experiment XVII.

Both diagrams show that the interindividual standard deviation increases with increased intermittent frequency. An exception to this is the visual intermittent frequency 12/sec.

Table 11.1. Experiment XVI.

Individual means for similarity matching between auditive intermittent frequency and velocity, values in r.p.m.
Descending series (a) and ascending series (b).

a. Intermittent auditive frequency (t.p.s.)

Subject no.	2	4	6	8	10	12
1	43.8	138.8	220.0	337.5	275.0	512.5
2	51.3	375.0	356.3	775.0	720.0	800.0
3	57.5	140.0	243.8	375.0	462.5	620.0
4	107.5	117.5	493.8	443.8	587.5	750.0
5	145.0	168.8	350.0	443.8	493.8	712.5
6	130.0	392.8	543.8	700.0	700.0	562.5
7	58.8	115.0	284.4	431.3	413.0	456.3
8	95.0	222.5	328.1	393.8	392.5	331.3
9	126.3	412.5	625.0	515.8	675.0	700.0
10	125.0	362.5	431.3	631.3	681.3	668.8
Mean	82.3	244.5	387.6	504.7	540.1	611.4

b. Intermittent auditive frequency (t.p.s.)

Subject no.	2	4	6	8	10	12
1	22.5	58.8	167.5	260.0	287.5	350.0
2	31.3	95.0	192.5	145.0	171.3	136.3
3	93.8	250.0	262.5	356.3	386.3	493.8
4	40.3	38.8	293.8	297.5	437.5	618.8
5	60.0	130.0	362.5	278.1	431.3	562.5
6	121.5	145.0	142.5	196.3	273.8	284.1
7	55.6	115.0	220.0	257.5	306.3	445.0
8	120.0	185.0	270.0	342.5	400.0	537.5
9	85.0	180.0	363.3	328.1	381.3	462.5
10	202.5	475.0	525.0	521.9	565.6	800.0
Mean	83.2	167.3	280.0	298.3	364.1	469.1

In Diagram 11.3 are given the plots of auditive and visual intermittent frequency against matched velocity. Here the difference between ascending and descending series is clearly seen. Further, it should be noted that while visual intermittent fre-

Table 11.2. Experiment XVI.

Individual standard deviations for similarity matchings between auditive intermittent frequency and velocity, values in r.p.m. Descending series (a) and ascending series (b).

a. Intermittent auditive frequency (t.p.s.)

Subject no.	2	4	6	8	10	12
1	16.2	23.7	76.8	12.5	25.0	37.5
2	1.3	75.0	206.1	25.0	50.0	15.8
3	2.5	20.0	6.2	50.0	12.5	50.0
4	27.5	7.2	81.3	81.2	112.5	0.0
5	75.0	146.3	62.5	229.4	168.8	62.5
6	10.0	207.5	93.3	25.0	0.0	12.5
7	1.3	5.0	3.1	118.8	56.3	43.8
8	37.0	52.5	3.1	43.8	57.5	81.3
9	12.5	137.5	25.0	15.7	50.0	100.0
10	45.0	112.5	93.8	143.8	68.7	131.2

b. Intermittent auditive frequency (t.p.s.)

Subject no.	2	4	6	8	10	12
1	0.0	43.8	107.5	105.0	12.5	25.0
2	3.8	15.0	17.5	0.0	1.3	26.3
3	31.5	170.0	12.5	43.8	31.3	81.2
4	3.1	11.3	6.2	102.5	87.5	93.6
5	5.0	75.0	12.5	84.4	93.8	25.6
6	3.8	45.0	12.5	3.8	83.7	9.1
7	1.9	2.5	55.0	105.0	56.3	25.0
8	0.0	15.0	80.0	157.5	15.8	62.5
9	15.0	0.0	225.3	71.9	118.8	50.0
10	57.5	175.0	225.0	115.7	28.1	0.0

quency is generally perceived as faster than auditive when descending matchings are made, this effect is not found for ascending series.

If Diagrams 11.1, 11.2 and 11.3 are taken together, it is just possible to discern a break occurring between the first three frequencies and the last three, i.e. between 6/sec. (360/min.) and

Table 11,3. Experiment XVII.

Individual means for similarity matching between visual intermittent frequency and velocity, values in r.p.m.
Descending series (a) and ascending series (b).

a. Intermittent visual frequency (l.p.s.)

Subject no.	2	4	6	8	10	12
1	175.0	380.6	575.0	687.5	697.5	700.0
2	113.8	254.4	575.0	565.0	712.5	615.0
3	42.5	135.0	156.3	212.5	185.0	255.0
4	387.5	502.5	800.0	762.5	677.5	975.0
5	581.3	350.0	675.0	565.0	740.0	637.5
6	115.0	437.5	775.0	700.0	762.5	856.3
7	197.5	210.0	231.3	418.8	450.0	575.0
8	583.8	725.0	837.5	887.5	987.5	850.0
9	83.8	337.5	750.0	756.3	762.5	687.5
10	125.0	175.0	235.0	300.0	467.5	631.3
Mean	240.5	350.8	561.0	585.5	644.2	678.3

b. Intermittent visual frequency (l.p.s.)

Subject no.	2	4	6	8	10	12
1	105.0	85.0	150.0	223.8	400.0	320.0
2	40.0	73.8	138.1	132.5	493.8	203.1
3	22.5	86.3	122.5	195.0	181.3	297.5
4	282.5	257.5	491.3	635.0	731.3	562.5
5	227.5	115.0	222.5	278.8	252.5	268.8
6	87.5	100.0	406.3	230.0	337.5	260.0
7	187.5	175.0	202.5	385.0	412.5	256.3
8	137.5	547.8	662.5	850.0	825.0	497.5
9	72.5	65.0	106.3	30.0	81.3	232.5
10	132.5	192.5	216.3	368.8	381.3	422.5
Mean	129.5	169.8	271.8	332.9	409.6	332.1

8/sec. (480/min.). This is in line with the observation made in Chapter 8. The indications are weak however and interindividual variability great.

The present results should be compared to the ones reported in Chapter 8—namely ratio estimation of auditive intermittent fre-

Table 11.4. Experiment XVII.

Individual standard deviations for similarity matching between visual intermittent frequency and velocity values in r.p.m. Descending series (a) and ascending series (b).

a. Intermittent visual frequency (l.p.s.)

Subject no.	2	4	6	8	10	12
1	25.0	25.6	25.0	62.5	52.5	100.0
2	36.3	39.4	50.0	35.0	7.0	40.0
3	12.5	15.0	6.3	32.5	35.0	20.0
4	25.0	97.5	0.0	12.5	222.5	25.0
5	31.3	25.0	75.0	165.0	22.5	162.5
6	55.0	122.5	0.0	50.0	12.5	43.8
7	77.5	15.0	31.3	18.8	50.0	25.0
8	3.8	25.0	62.5	37.5	62.5	100.0
9	28.8	187.5	0.0	18.8	37.5	62.5
10	5.0	5.0	15.0	25.0	132.5	168.8

b. Intermittent visual frequency (p.s.)

Subject no.	2	4	6	8	10	12
1	70.0	35.0	25.0	112.5	100.0	30.0
2	10.0	43.8	31.9	12.0	193.8	153.1
3	0.0	38.8	47.5	25.0	18.8	22.5
4	162.5	122.5	46.3	10.0	231.3	262.5
5	18.8	5.0	52.5	96.3	22.5	6.3
6	57.5	45.0	331.3	5.0	50.0	15.0
7	2.5	45.0	47.5	65.0	112.5	31.3
8	112.5	77.5	57.5	50.0	125.0	202.5
9	47.5	15.0	116.3	5.0	38.8	192.5
10	2.5	17.5	33.8	18.8	81.3	22.5

quency and silent velocity (Experiments VIII and X). From Table 8.11 an S-R-S diagram for velocity–R scales–auditive frequency is plotted. By using curves fitted by inspection it is possible to get an approximate similarity relation between auditive intermittent frequency and velocity, which is given in Table 11.5.

The velocities matched in Experiment XVI are more than double the ones given in Experiment VIII and Experiment X.

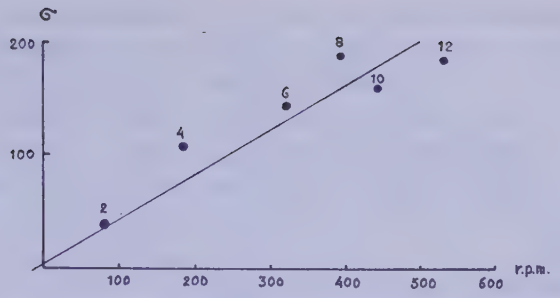


Diagram 11.1 Experiment XVI. Interindividual σ as a function of silent velocity matched to auditive intermittent frequency. $\sigma = 0.388\,S + 5.969$.

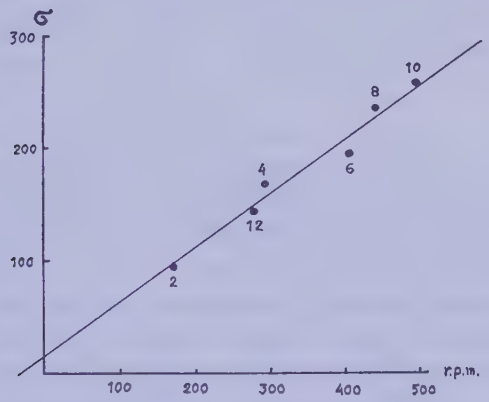


Diagram 11.2 Experiment XVII. Interindividual σ as a function of silent velocity matched to auditive intermittent frequency. $\sigma = 0.480\,S + 14.296$.

11.2.5 *Discussion*

Our results indicate that subjects function with far less precision in the similarity matching task than in the ratio estimation task. The inter- and intraindividual variations are greater in the similarity matchings. If the two tasks are compared, certain differences are obvious. In ratio estimation the subject is given a zero point and a scale with a unit, and usually he knows (by school education) how to handle the scale. He is further instructed to compare two experiences directly on a common attribute.

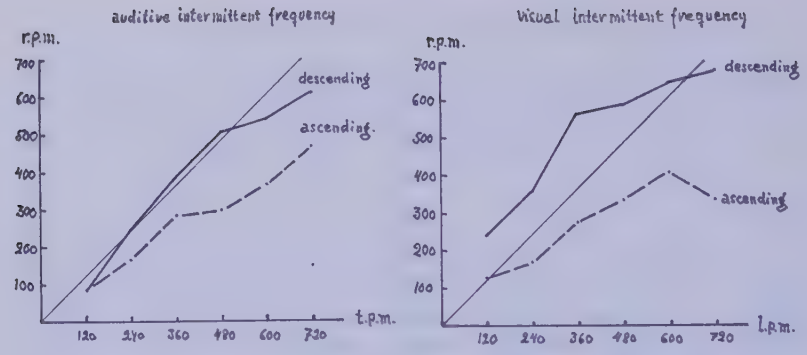


Diagram 11.3 Experiment XVI and XVII. Similarity matchings between auditive and visual intermittent frequency (tones per minute and lights per minute) and silent velocity. Group curves.

Table 11.5.

Comparison of similarity estimates from Experiment VIII and Experiment X, ratio estimation, and Experiment XVI, method of reproduction.

Auditive intermittent frequency		Exp. VIII & X r.p.m.	Exp. XVI r.p.m.
t.p.s.	t.p.m.		½ (ascending + descending)
2	120	40	83
4	240	90	206
6	360	120	334
8	480	140	402
10	600	160	452
12	720	195	540

In similarity matching the subject is left free to choose his own zero point and evaluate the scale he is going to use. (It is further required that he transforms one of his experiences into active manipulation. His matching is the result of comparing two experiences, one of which is varied via motor responses.)

Letting a subject choose his own zero point and scale should provide considerable variability. It may further be assumed that

a subject free to choose his own frame of reference will be more apt to be influenced by the context, e.g. high and low starting point. Because of these factors similarity matching by reproduction is perhaps a more complicated task than ratio estimation—at least for adult subjects well trained in quantitative comparisons.

During sessions it was observed that very few subjects used the total velocity range. They bracketed around their final matching within a restricted range.

The difference between similarities found in ratio estimation and matching by reproduction may tentatively be described in terms of anchor effects. The initial "anchors" in the reproduction experiments were 20 and 750 r.p.m., while the corresponding anchors in ratio estimation were 20 and 153 r.p.m.

These effects also provide an explanation of the difference between ascending and descending matching series.

Why visual intermittent frequency is perceived as "faster" than a corresponding auditive intermittent frequency cannot be adequately explained at present. Goldstone, Boardman and Lhamon (op. cit. Chapter 10) report some data. They compared estimates of 1-second intervals filled with auditory and visual stimuli, using the method of limits. The estimates of visually filled intervals were found to be roughly double the length of auditory filled intervals. This implies that if the amount of change is constant, visual intervals are judged as longer, i.e. the time goes faster. In the present experiments this means that the visual intermittent frequency should be judged faster than the auditory. It should be noted that different subjects participated in the present two experiments. Bearing the great variability of data in mind, the difference observed may be interpreted as random error. However the size and systematic trend of the difference makes this interpretation unlikely. It must also be remembered that both auditive and visual intermittent frequency were presented *simultaneously* with the velocity. The possible sensory interaction that may occur here is not under control. However, similar possibilities for this effect are present for both types of intermittent frequency. If the difference is accepted as systematic, it follows that a visual intermittent frequency ought to give rise to a greater sensory interaction effect,

if it is used as a "load" on velocity in a ratio estimation task of the type earlier reported. Further this prediction is based on the assumption that the auxiliary and basic stimulus components are somehow combined. Some evidence for this has already been reported in Chapters 6 and 7.

The prediction will be tested in the next two experiments in this chapter.

The three problems stated for these experiments have been answered thus:

1. Subjects can do similarity matchings between auditive and visual intermittent frequency and silent velocity. Group data appear fairly consistent, but there is great inter- and intra-individual variation, and subjects are markedly affected by the starting velocities.
2. Corresponding auditive and visual intermittent frequencies are not matched by the same velocities. As a rule a visual intermittent frequency is perceived as "faster" than the corresponding auditive frequency.
3. The similarity matchings by reproduction and those from ratio estimation do not agree. The disagreement is tentatively described in terms of anchor effects.

The results of matching experiments reported above show too great a variability to be usable in equalizing scales from silent and loaded velocity and intermittent frequency as was suggested in Section 11.1.

11.3 *Two ratio estimation experiments XVIII and XIX*

11.3.1 *Problems*

The aim of Experiment XVIII and Experiment XIX is to study the predicted change in sensory interaction effects, when velocity is loaded with auditive and visual intermittent frequency respectively.

In addition, the previously mentioned analysis of dimensionality and internal consistency are made.

11.3.2 *Apparatus and subjects*

The apparatus was the same as was used earlier, see Appendix I and Section 11.2.2.

As subjects participated 6 students of psychology, 4 female and 2 male. Age range: 20–30 years. The median age was 21.5 years.

All six subjects performed both experiments. Three of the subjects started with Experiment XVIII and three with Experiment XIX.

11.3.3 *Procedure*

The earlier presented generalized ratio estimation method was used.

Each velocity (20, 36, 60, 90, 113, 153) is presented together with a loaded velocity. In Experiment XVIII the loading is auditive intermittent frequency of 12 t.p.s.; in Experiment XIX the loading is visual intermittent frequency of 12 l.p.s.

The subjets are instructed to give ratio $\gtrless 1.00$ for each pair of velocities, so that silent velocity is the standard stimulus and loaded velocity the variable. No pre-trials were run.

The 6×6 stimuli pairs were randomized to balance temporal order and spatial position. Each stimuli pair was judged 4 times. The presentation time for each pair was standardized S_1-2 seconds, S_2-2 seconds.

Each session lasted for $2^1/_4$–$2^1/_2$ hours. Sessions were run without rest pauses.

Most subjects found the experiments tiresome.

11.3.4 *Results*

Geometrical means are computed on the four ratios in each individual cell. The scales are computed in the conventional manner.

Individual scales are given in Table 11.6 for Experiment XVIII and Table 11.7 for Experiment XIX.

In Table 11.8 and Table 11.9 are given the differences between individual loaded and silent scale values for the two experiments.

Table 11.6. Experiment XVIII.

Auditive intermittent frequency 12/sec. Individual scale values for silent (a) and loaded velocity (b).

a. Velocity in r.p.m.

Subject no.	20	36	60	90	113	153
1	2.42	4.29	7.55	11.05	14.37	16.51
2	2.99	3.57	7.04	9.08	12.07	19.67
3	2.37	4.52	7.25	10.65	13.80	19.04
4	2.28	4.03	7.80	13.05	16.04	21.96
5	2.53	3.90	7.89	10.90	12.64	19.65
6	3.53	4.23	5.49	7.60	9.72	15.67
Mean	2.59	4.05	7.17	10.29	13.02	18.74

b. Velocity in r.p.m.

Subject no.	20	36	60	90	113	153
1	2.74	3.82	7.22	11.30	14.43	17.49
2	2.59	3.98	6.10	10.30	12.76	23.21
3	2.51	3.71	6.96	11.16	14.46	19.62
4	2.22	3.98	7.32	11.96	17.17	22.00
5	2.51	4.10	7.03	11.23	15.47	19.35
6	2.84	4.66	6.34	7.07	9.70	11.93
Mean	2.57	4.03	6.83	10.51	14.17	18.94

The mean differences and these differences in percent of the corresponding mean silent scale value are given in Diagram 11.4 and Diagram 11.5 respectively.

As seen from Table 11.6 and Table 11.8 and Diagram 11.4, the sensory interaction for auditive frequency is similar to that found earlier. It must be remembered that the effect is built on two components—as shown in Chapter 9—one depending on the different evaluation of stimuli appearing as standard and variable, the other depending on the auditive frequency.

If Diagrams 11.4 and 11.5 are compared, it is seen that the visual intermittent frequency gives a different sensory interaction effect than the auditive frequency. The visual intramodal effect is

Table 11.7. Experiment XIX.

Visual intermittent frequency 12/sec. Individual scale values for silent (a) and loaded velocity (b).

a. Velocity in r.p.m.

Subject no.	20	36	60	90	113	153
1	2.74	4.02	7.08	10.24	11.92	15.74
2	2.69	3.41	8.06	11.08	13.30	22.33
3	2.61	3.94	6.63	11.54	14.34	17.92
4	3.44	3.88	6.07	7.71	10.88	15.43
5	3.40	4.13	5.63	8.72	10.24	13.56
6	3.41	4.64	6.19	7.60	8.69	12.13
Mean	2.97	3.93	6.61	9.36	11.43	15.95

b. Velocity in r.p.m.

Subject no.	20	36	60	90	113	153
1	2.58	4.21	6.67	10.88	13.70	15.23
2	2.32	4.60	9.19	10.94	15.84	27.92
3	2.80	4.55	7.69	10.47	14.47	19.04
4	2.84	4.51	6.67	9.89	12.43	18.07
5	2.95	4.42	7.04	10.16	9.70	11.87
6	3.26	5.11	7.29	8.52	11.62	14.86
Mean	2.79	4.56	7.43	10.14	12.96	17.83

more marked and does not disappear or reverse at the higher velocities. If Tables 11.8 and 11.9 are compared, it is seen that the last part of this description does not hold at the individual level. This point is taken up in Section 11.2.5.

For Experiment XVIII and Experiment XIX the internal consistency has been tested by computing

$$qij = qkj \cdot qih/qkh$$
$$\text{where } k \neq i$$
$$h \neq j$$

on each individual matrix and the group matrix of each experiment. The arithmetic means of the computed ratios are plotted against

Table 11.8. Experiment XVIII.

Auditive intermittent frequency 12/sec. Difference between loaded and silent scale value for each subject. $\overline{\text{Diff}}$ = mean difference computed over 6 subjects. $\overline{\text{Diff.\%}} = \overline{\text{Diff.}}$ given in percent of respective group mean silent scale value.

Subject no.	20	36	60	90	113	153
1	0.32	—0.47	—0.33	0.25	0.06	0.98
2	—0.40	0.41	—0.94	1.22	0.69	3.54
3	0.14	—0.81	—0.29	0.51	0.66	0.58
4	—0.06	—0.05	—0.48	—1.09	1.13	0.04
5	—0.02	0.20	—0.86	0.33	2.83	—0.30
6	—0.69	0.43	0.85	—0.53	—0.02	—3.74
$\overline{\text{Diff.}}$	—0.016	—0.025	—0.34	0.218	1.151	0.198
$\overline{\text{Diff.\%}}$	—0.62	—0.62	—4.74	2.12	8.83	1.06

Table 11.9. Experiment XIX.

Visual intermittent frequency 12/sec.Difference between loaded and silent scale value for each subject. $\overline{\text{Diff.}}$ = mean difference computed over 6 subjects. $\overline{\text{Diff.\%}} = \overline{\text{Diff.}}$ given in percent of respective group silent scale value.

Subject no.	20	36	60	90	113	153
1	—0.16	0.19	—0.41	0.64	1.78	—0.51
2	—0.37	1.19	1.13	—0.14	2.54	5.59
3	0.19	0.61	1.06	—1.07	0.13	1.12
4	—0.60	0.63	0.60	2.18	1.55	2.64
5	—0.45	0.29	0.85	1.44	—0.54	—1.69
6	—0.15	0.47	1.10	0.92	2.93	2.73
$\overline{\text{Diff.}}$	—0.174	0.63	0.815	0.784	1.528	1.877
$\overline{\text{Diff.\%}}$	—5.86	16.28	12.33	8.38	13.37	11.79

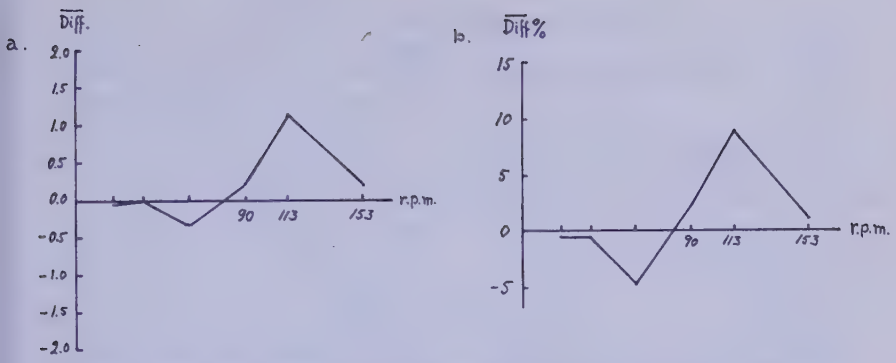


Diagram 11.4 Experiment XVIII, auditive intermittent frequency.
a. Compared velocities plotted against mean difference between loaded and silent scale value, (Diff.). b. Diff. given in percent of mean silent scale value, (Diff %).

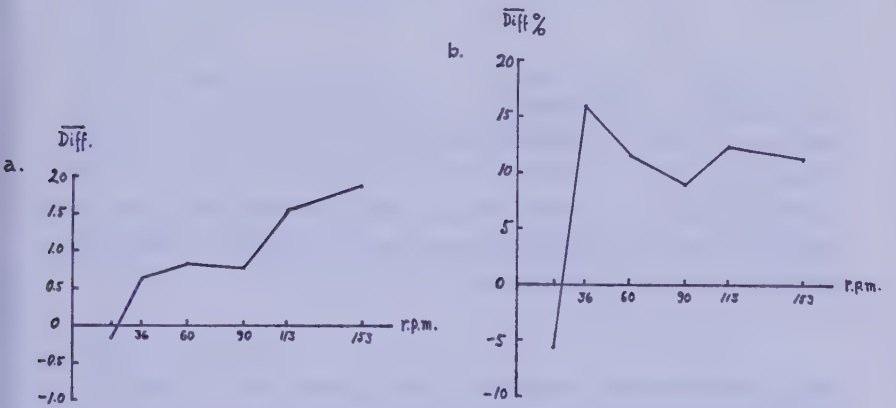


Diagram 11.5 Experiment XIX, visual intermittent frequency.
a. Compared velocities plotted against mean difference between loaded and silent scale value, (Diff.). b. Diff. given in percent of mean silent scale value (Diff %).

the empirical ratios. The linearity of the plots are good for all subjects. The plots from the group matrices are given in Diagram 11.6 for Experiment XVIII and Experiment XIX. It has earlier been shown that the consistency test is valid if the matrices are

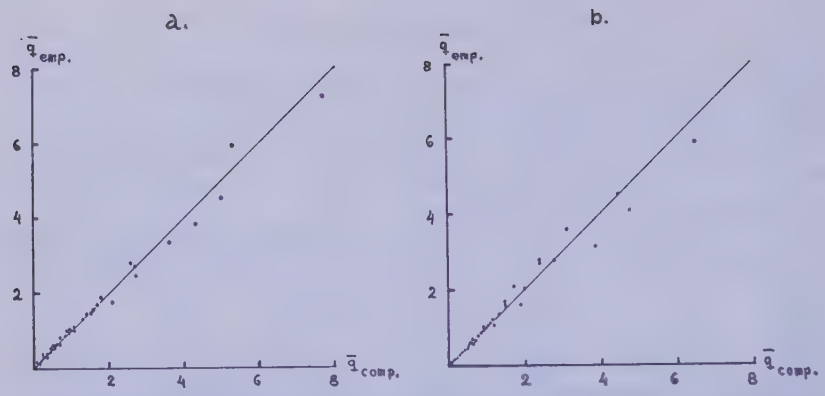


Diagram 11.6 Plot between the mean of computed ratios, $\bar{q}_{comp.}$ and empirical ratios, $q_{emp.}$.
Group matrices. a. Experiment XVIII, auditive intermittent frequency.
b. Experiment XIX, visual intermittent frequency.

unidimensional. The group matrices have been analyzed by factor-analysis. The result from this analysis is given in Table 11.10 for Experiment XVIII and in Table 11.11 for Experiment XIX. Provided the assumption underlying the procedures holds true, the matrices from the two experiments may be considered unidimensional and internally consistent.

11.3.5 *Discussion*

All of the individual relative effect curves, irrespective of whether they reflect auditive or visual intermittent loading effects could be described by a function of the principal form:

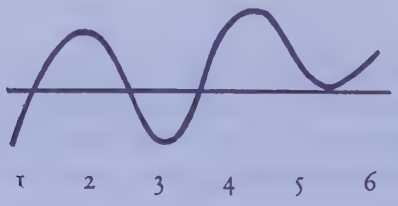


Table 10.10. Experiment XVIII.

Auditive intermittent frequency 12/sec. Factor analysis of group matrix. Trace = 193.222.

Latent root no.	Absolute value of latent root	Cumulative sum of latent root	Cumulative prop. of trace
1	182.804	182.804	0.998
2	0.338	183.143	1.000
3	0.068	183.211	1.000
4	0.009	183.219	1.000
5	0.003	183.222	1.000
6	0.000	183.223	1.000

Table 11.11. Experiment XIX.

Visual intermittent frequency 12/sec. Factor analysis of group matrix. Trace = 150.157.

Latent root no.	Absolute value of latent root	Cumulative sum of latent root	Cumulative prop. of trace
1	149.464	149.464	0.995
2	0.616	150.080	0.999
3	0.072	150.152	1.000
4	0.003	150.155	1.000
5	0.002	150.157	1.000
6	0.000	150.157	1.000

Subjects appear to vary little as to their starting position. 9 out of 12 start at position 1. 2 of the remaining 3 start at position 2, while the remaining subject may be seen as starting either at position 1 or 3.

Of the 11 subjects starting at position 1 or 2, 4 end at position 6, 5 at position 5 and 2 at position 4. The remaining subject (seen as starting at position 1 or 3) ends up at position 3 or 5.

The main descriptive curve given here should be compared to the results from Experiment XI reported in Chapter 9. In that experiment only four velocities were used (60, 90, 113, 153), and the resulting individual relative effect curves in that case lie

between position 3 and 6. This also holds when the standard/variable effect is eliminated.

A more thorough discussion of this point will be given in Chapter 12, where the present series of experiments are discussed in toto.

The observed greater effect of visual intermittent frequency as compared to auditive frequency deserves some attention. In Section 11.2.5 it was observed that visual frequency was perceived as "faster" than auditive frequency when both were separately matched against visual velocity. (Direct matchings of auditive and visual frequency were not made.) This finding gave rise to the prediction that visual intermittent loading on velocity should also give greater sensory interaction effects in a ratio estimation task, provided that the auxiliary and basic stimulus components are additively continued. This prediction is verified in the present experiments. Earlier experimentation reviewed in Chapter 4, and discussed in Section 11.2.5, shows that intramodal interaction is usually stronger than intermodal. This observation in itself does not however explain why visual frequency is perceived as faster than auditive in the matching experiments. We thus have two lines of argumentation:

a) Visual frequency is perceived as faster than a corresponding auditive frequency. The two velocity experiences are combined in some additive combination and the faster the parts, the faster the resultant perception.

b) An intramodal sensory interaction is generally more effective than an intermodal. On the one hand this may explain the higher visual similarity matchings either because of sensory interaction or because of a greater effectiveness of intramodal anchors. On the other hand the intramodal stimuli-combination may be more apt to be subjectively combined. Which one of these explanations is the more adequate could not be determined.

11.4 *Summary and conclusion*

Four experiments are reported. Two are similarity matchings with the method of reproduction of auditory or visual intermittent

frequency and velocity. Two are ratio estimation of silent velocity and velocity loaded with auditory and visual intermittent frequency.

The general aim of the matching experiments was to obtain data for use in equalizing scales of silent velocity, loaded velocity and intermittent frequency. Although the subjects as a group showed some consistency in their matchings, marked serial effects and great inter- and intraindividual variability in the data makes it unusable for the intended purpose.

It was also found that visual intermittent frequency was judged as faster than a corresponding auditory frequency. The results of the ratio estimation experiments are in line with previous experimentation. For visual frequency, more marked sensory interaction effects were found. The relative difference-curves between silent and loaded velocity are similar in form for auditory and visual loading.

Both experiments give unidimensional and internally consistent response matrices.

Discussion and conclusions

12.1 *The problems*

The principal attribute under study is velocity or more specifically the velocity of circular motion. In an experiment by Johansson (1950) the effect of auditively heard intermittent frequencies was shown to affect similarity matchings (method of reproduction) of two velocities so that the velocity associated with the higher frequency was overestimated relative the other velocity. This was seen as an example of sensory interaction between seeing and hearing.

In this work the noticed effect is studied further and attempts are made to specify, restate or solve two main problems:

1. Is there a sensory interaction effect for the attribute of velocity?
2. If so can this effect be measured by psychophysical scaling methods?

The two problems are intricate as they are by no means independent of each other.

Sensory interaction has here been defined as a permanent or temporary change in response to a given stimulation occurring when a simultaneous auxiliary stimulation is added (inter- or intra-modally) (Chapter 2). In the following discussion (Chapter 3) it is shown that sensory interaction is difficult to distinguish from effects known by other names. The review of some earlier investigations (Chapter 4) shows that the concept of sensory interaction is made still vaguer through differential application of the term in different studies. The review ends up by stating that problem 1 with its original object must be modified. However, used as a subsumption in Helson's sense (op. cit.) it still functions on a classificatory level. An answer to problem 1 thus implies that a distinction can be made between the effects of auxiliary stimula-

tion and possible methodological artifacts. In Section 4.7 problem 1 and 2 are reformulated:

1. Can the influence of auditory stimulation on velocity perception (here called sensory interaction) be measured by psychophysical scaling methods.
2. Do data from scaling experiments reveal anything beyond changes in the subjects response-habits (i.e. response-bias).

If an effect is measured by a scaling procedure it must be clear that the effect is not caused by methodological artifacts or that it reflects solely a change in the subjects' use of the response language.

Evidence at hand from the discussions and review in Chapter 2, 3 and 4 gave rise to the six subsumptions put forward in Chapter 5.

1. A sensory interaction effect should be found when silent and auditory loaded velocity estimates are compared.
2. The effect can be measured by ratio estimation, magnitude estimation and paired comparisons.
3. The effect is different for different velocities.
4. The effect is different for different auditive loadings.
5. Individuals are differentially susceptible to the effect.
6. The effect changes in a systematic manner over trials.

These six subsumptions are studied and discussed in all the experiments carried out an reported in Chapters 6, 7, 8, 9, 10, 11.

A number of specific questions tied to the problem of distinguishing between sensory interaction (as it is defined here) and different types of artifacts and response-bias are taken up at different stages. They are mentioned in chronological order in Chapter 5 and may be summarized as concerning:

a. internal consistency of data
b. dimensionality of data
c. unit of measurement
d. response-language
e. data models
f. inter-method comparisons

If response-bias and methodological artifacts can be ruled out as explanatory concepts for the effect under study, there is left an effect that, according to the argument in chapter 1 can be regarded as an indicant of a true change in perception.

12.2 *Is there a sensory interaction effect which is measurable with psychophysical scaling methods?*

Of the nineteen experiments reported here, twelve try to measure sensory interaction effects on velocity. Of these twelve experiments, seven are ratio estimation, four are magnitude estimation and one is paired comparisons of loaded and silent velocity.

In all these experiments, differences are found between estimates of loaded and silent velocity. The data body does not contradict the idea of a sensory interaction effect. However the findings do not rule out alternative explanatory mechanisms. In general, the differences found are in accordance with the earlier results of Johansson (ibid.). In both ratio and magnitude estimation it is shown that the lowest and highest loaded velocities give small or negative effects while ratio estimation in addition gives negative effects for intermediate velocities. These phenomena were not reported by Johansson. Another discrepancy between Johansson's results and mine is that his differences were obtained between velocities loaded with different intermittent frequencies while I compared a zero-loaded set of velocities with a loaded set. When I compared the effect of different intermittent frequencies with silent velocity, no or at least very small differences were found. The results were similar for both ratio and magnitude estimation.

The relative effect curve is thus not similar for ratio and magnitude estimation. Ratio estimation yields, roughly speaking, inverted w-curves while magnitude estimation yields negatively accelerated or inverted u-curves. The results from paired comparisons only indicate that the mean effect measured over stimuli and over a comparable number of trials is in the same direction as that found with the other two methods.

Before the observed general effect could be regarded as a sensory interaction, methodological factors should be ruled out and I will

discuss these before discussing the discrepancy mentioned above.

Conventional testing of internal consistency could not be carried out as nonidentical sets of stimuli are used in the ratio estimation experiments.

For ratio estimation, a method of calculating and comparing computed and empirical ratios is presented which is applicable to ratio matrices from nonidentical sets of stimuli, if these matrices are unidimensional. By factor analysis unidimensionality is shown for individual and group matrices and plots of computed and empirical ratios are shown to be linear. According to the procedure used, data from ratio estimation are unidimensional and internally consistent. This does not, however, completely rule out the possibility that the procedure is insensitive to certain types of inconsistency.

Acording to Ekman (op.cit.) the variant of ratio estimation used here yields two scales in the same unit of measurement. In chapter 8 it was shown by comparing experiments using silent stimuli as standards, with those using loaded stimuli that the unit of measurement is changed. Transforming one set of scales into the same unit does however not fully restore comparability. The relative effect curve between loaded and silent velocity is however unaffected. This indicates that the intermittent frequency has an effect and that some methodological artifacts apart from this effect remain. This finding may in part explain the different relative effect curves found with ratio and magnitude estimation.

The bimodal relative effect curve found for ratio estimation and the findings summarized above led to the suspicion that the data model proposed by Ekman (ibid.) may be inadequate. Instead it is assumed that identical stimuli are evaluated differently when they are perceived as standard and variable and that intermittent frequency has an effect quite apart from this standard/variable effect. This data model—orignally suggested by Sjöberg (op.cit.) for conventional ratio estimation—is used in an experiment where both the silent and the loaded stimuli sets served as standards and variables in the same data matrix (chapter 9). Here it was possible to isolate the effect depending on differential standard variable evaluation of stimuli from that of intermittent frequency. The

"pure" sensory interaction effect was described by an inverted u-curve for the range investigated.

Magnitude estimation methods are usually considered to be more free of inconsistencies of the sort described above, and I am thus inclined to regard the relative effect curves from these experiments as providing a more adequate description of the sensory interaction effect. The consistency testing carried out for this method consisted in comparing and plotting scales from conditions using different stimuli as standards. The results from these indicate an acceptable consistency. The relative effect curves found in magnitude estimation are, as mentioned above, negatively accelerated curves or inverted u-curves.

The experiment with paired comparisons did not allow any testing of consistency as the difference between loaded and silent curves there was taken as a mean over 20 stimulus-pairs.

In both ratio and magnitude estimation it was found that different velocities were differentially affected by the intermittent frequency (chapters 6, 7, 8, 9, 11). As a general tendency it could be said that low velocities show a small or negative effect while intermediate velocities are affected most and high velocities somewhat less. This description does not fit the data from ratio estimation where a negative dip is found for intermediate velocities.

This dip could tentatively be explained as a combined effect of sensory interaction and the standard/variable effect. The sensory interaction curve (SI) is assumed to be described by an inverted U-function (from the results of magnitude estimation and ratio estimation of complete matrices). The standard/variable curve (SV) is assumed to be described by a U-function (from the results of ratio estimation of complete matrices, and Sjöberg (ibid.). The principal form of the two curves are given in Figure 12.1 a and b.

If the SI curve is assumed to increase faster than the SV curve decreases and reach its maximum after the SV curve reaches its minimum and if further the relation of increase/decrease is maintained after the max/min points are reached, an additive combination of SI and SV, taking care of the sign of respective effect, gives a resultant curve that is similar in form to that found in the

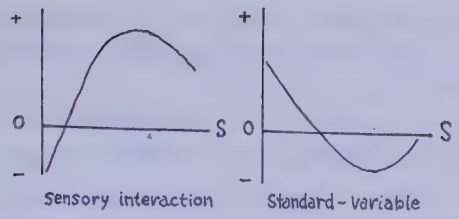


Figure 12.1 Principal effect curves assumed for sensory interaction and standard-variable evaluation.

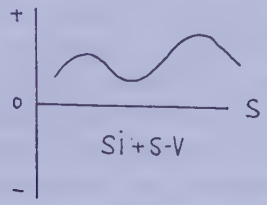


Figure 12.2 Sensory interaction curve + standard-variable curve.

ratio estimation experiments. Its principal form is shown in Figure 12.2.

As shown in all experiments, the individual effect curves do vary. The variation could be described by assuming that individuals are differentially susceptible to sensory interaction at the same time as they vary in their evaluation of the speed of the intermittent frequency (see chapter 11). In terms of the model given in Fig. 12.1 it can be said that the o-line and the growth rate of the SI and SV curves do vary interindividually. It is thus plausible to expect different forms and levels of the SI + SV-curve given in Fig. 12.2.

The three methods used vary in their degree of refinement as regards the response-language employed. Two of them—ratio and magnitude estimation—easily induce response-bias. By response-bias is here understood that subjects could produce the sensory interaction (and the standard/variable effect) by changes in his response-language. The differences found thus may not reflect a true change in perception. Paired comparisons and the method of reproduction (used by Johansson) on the other hand are free from

this type of response-bias. The results from these experiments show the same effects indicating that the subjects have in fact changed their perceptions.

The effect found is thus seen as indicating changes in perception according to the definition given in chapter 1.

12.3 *Changes of sensory interaction effect for different velocities*

Johansson (ibid.) tentatively explains his results by proposing that velocity perception is a combination of two components, one temporal and one spatial. In the present type of sensory interaction the temporal component is affected. The flow of the time stream is changed. The experiments of Frankenhauser (op. cit.) and the paired comparisons of silent and loaded time in the present study show that if time is the attribute judged this is true. Johansson's explanation would however lead to the conclusion (indirectly confirmed in the time experiments) that a constant difference between loaded and silent velocity should be found. This is not the case. Instead the sensory interaction is negative or small for low velocities, high for intermediate and small for high velocities. Factor analysis of ratio estimation matrices of velocity and intermittent frequency showed a clear unidimensionality (Chapter 8). This could either be interpreted as time (or frequency) being judged in both stimuli or that velocity (or speed) is judged in both stimuli. As the intermittent frequencies used were both below and above the counting ability threshold and no marked inconsistencies were found (except for the breaks in S-R plots) I am more inclined to assume that speed is the attribute judged. This assumption is indirectly confirmed by the similarity matchings of intermittent frequency and velocity reported in Chapter 11. (It is just possible that a break occurs between the matchings of 2, 4. 6. and 8, 10, 12 tones or lights per second in both the standard deviation plots given in diagrams 11.1 and 11.2 and in the mean matchings given in Diagram 11.3. As the data show interindividual variability this interpretation is very uncertain.)

From the data available at present it is not possible to determine which of the two explanations that is the more adequate.

The assumption put forward by me implies that the subject somehow combines the heard speed and the seen speed. How this combination is made is unclear. One possibility is that the visual speeds set up an AL. The heard speed is assimilated, equalized or contrasted to this AL and also to the actual seen speed, according to the reasoning of Helson (1964 page 282). Helson has not himself worked with sensory interaction problems but indicates (ibid. page 73) that it is possible. For low visual speeds contrast or equality occur, while different degrees of assimilation are found at higher visual speeds. The intermittent frequency generally used—12/sec—is, as seen from Table 11.5, always perceived as faster than any of the visual speed presented. A finding somewhat hard to fit into this explanation is the very slight difference in effect found for intermittent frequencies of 5/sec and 12/sec and reported in Chapter 6 and 7. Similarity matchings with the two methods used indicate, however, that 5/sec is also perceived as equal to the fastest of the visual speeds. (Note the difference between ratio estimation and method of reproduction.)

This explanation is not compatible with the ones given by Johansson in terms of a changed flow of the time stream and by Frankenhauser in terms of changes in mental content. It is also hard to see how these two explanations could describe the differential effect on different velocities unless a third effect is assumed to be at work on the end stimuli in ratio and magnitude estimation. An argument against this is that the standard/variable effect, as it is assumed to work, functions as an end-effect as well.

12.4 *Changes of sensory interaction effect over trials*

In some of the ratio and magnitude estimation experiments (chapters 6, 7, 8 and 9) an analysis was made on how the effect changes over trials. In general the loaded scale values changed more than the silent values. This finding is in line with the prediction made by Sokolov (op. cit. Chapter 4 section 3). He explains this type of effect in terms of the orienting reflex which is thought to be aroused as soon as a new stimulus is introduced. When the new stimulus is repeated the orienting reflex is extinguished. Thus

according to Sokolov the effect should disappear with repeated exposure. This is however not the case in the present experiments. Although the data are not unequivocal, the general trend is that the effect is greatest on the first trial, disappears or is reversed on the next two and reappears on the fourth trial. Some data (Chapter 8) indicate that the direction of change might be reversed for silent and loaded velocity as well as for low and high velocities. It is tentatively suggested that the silent scale is rotated in a clockwise direction while the loaded scale is rotated in counter-clockwise direction. The paired comparisons presented in Chapter 10 give additional information on the general change of effect. The results coincide with those from ratio and magnitude estimation for the corresponding four trials but the change continued in a cyclical manner over the twenty trials studied.

The combined findings do not fit the prediction inferred from the Sokolov theory (ibid.). It is difficult to think up alternative explanations. The changes found appear irrespective of knowledge of results. They are of a magnitude comparable to that found from training on the Müller-Luyer illusion (reported in Chapter 10). The cyclical pattern of change is also found here.

Similarity on the data level with findings from perceptual learning studies (see e.g. Wohlwill (1958), Bauer (1963) and Englund and Lundberg (1963)) indicate that the present phenomenon may be handled with the same types of explanatory concepts. A difference is that the present effects do occur over very few trials whereas the perceptual learning effects as a rule are measured over a great number of trials. In the present experiments no such comparisons or analysis are made for these reasons.

12.5 *Sex differences and differential susceptibility to sensory interaction.*

In several of the studies reviewed in Chapter 4 it was noted that female and male subjects are differentially susceptible to sensory interaction effects. An individual differential susceptibility was also noted by other workers, e.g. Johansson (ibid.). In Chapter 6 and 7 the interindividual variation was specifically studied. It was

incidently noted that male subjects as a group show smaller effects than female subjects. Using magnitude estimation (Chapter 7) it was found that male and female groups showed markedly different relative effect curves. The sex differences are however not traceable down to the individual level where the same typical effect curve is found varying in relation to the o-level and the S-range. It is suggested that the sex differences found are spurious effects of a marked interindividual variation irrespective of sex. As was mentioned in section 2 of this chapter, subjects could be seen as varying in o-level and in their evaluation of intermittent frequency. This does not imply that the main form of the sensory interaction curve is changed but rather that the parameters of the function are individually determined.

12.6 *Summary of conclusions*

The outcome of the reported series of experiments may be summed up in the following six points:

1. A sensory interaction effect is found when silent velocity and velocity loaded with an auditive intermittent frequency are compared.
2. The effect appears to be measurable by ratio estimation, magnitude estimation and paired comparisons.
   Ratio estimation measures sensory interaction combined with effects of methodological artifacts. Making certain assumptions concerning data and with a specific stimulus combination it is possible to isolate a pure sensory interaction effect.
3. The effect is shown to change systematically over the range of velocities studied.
4. It is not shown to be affected by low and high intermittent frequencies.
5. Almost all subjects studied are susceptible to the effect although marked interindividual variation is found.
6. The effect is found to vary in a cyclical manner over trials. It is in general found to be greatest on the first trial.

Appendix I

I.1 *Apparatus*

The equipment used in ratio and magnitude estimation and in paired comparisons is given in Figure I.1. The apparatus consists of two units: one displaying the moving lightspots, the other producing the intermittent frequency. The two units are coupled together.

The unit displaying the moving lightspots consists of two gear systems: one with 8 fixed steps, the other allowing continuous variation of the velocity between 10–200 r.p.m.

In experiments I to X and XVIII and XIX, the continuous gear system marked B_1 in Fig. 1 was used to produce one of the speeds (alternating silent and loaded). It consisted of two cones, lying parallel, the velocity of one cone being transmitted via a movable wheel to the other cone and thus variable. In experiments XI and XII this part of the gear system was replaced by a motor-controller (type Servomex) marked B_2 in Fig. 1. The subject is seated 2–2.5 m in front of a semi-transparent screen (80 × 80 cm). By pressing or releasing a switch he sees a moving spot (diam. = 0.5 cm) moving in a circular track (diam. = 14 cm) or another similar spot accompanied by an intermittent auditive (or visual) frequency, see Fig. I.2. The two circular tracks appear side by side (distance between tracks 3 cm).

The auditive intermittent frequency is produced by a tone-generator (Philips GN 2306 C) coupled to a timer and a pair of earphones (Maico). The tonepulses have a gradual onset to avoid "knockings"–see Fig. I.3. The on-off ratio is always equal to 1. The tone is 800 cps and the loudness 82.5 db.

The visual frequency (used in experiments XVII and XIX) is produced by a strobotac timer and a strobotac lamp attached to the lower edge of the screen–see Fig. I.1. The strobotac lamp is shaded from the subject and adjusted to spread the light evenly

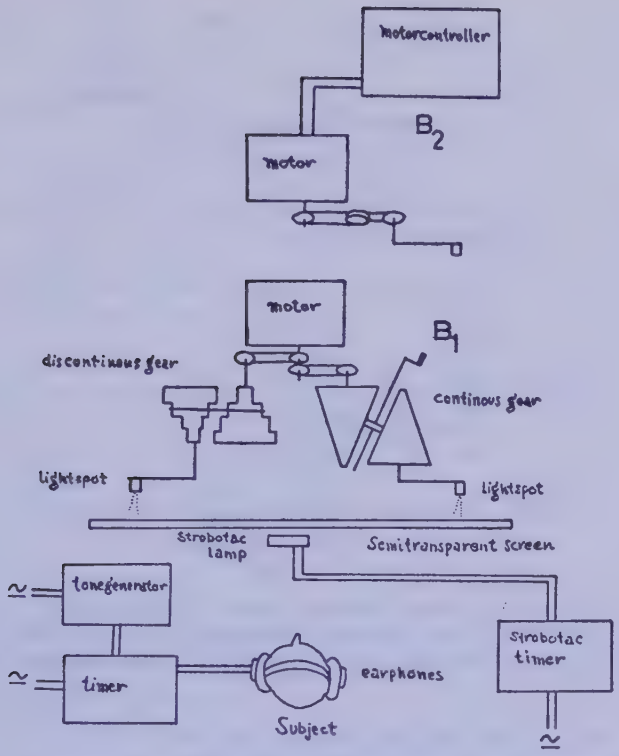


Figure I.1 Apparatus used in the present experiments. For a detailed description and explanation see the text.

over the screen. The on-off ratio is variable and the lightpulses, irrespective of the intermittent frequency used, are of a constant duration (c:a .1 ms).

All experiments are run in a semidark room. The apparatus itself spreads some light producing shadows of the moving shafts on the screen. To eliminate this, additional shaded lamps are placed so that these shadows disappear.

In the similarity matching exepriments (XVI and XVII) a modified setup is used. It is shown in Fig. I.4.

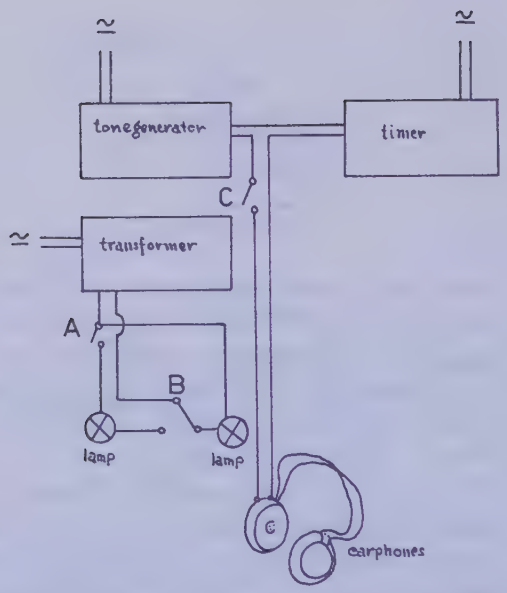


Figure I.2 Coupling diagram between moving light spots and intermittent frequency. The switches at A, B and C are synchronized and handled by the subject or (in Experiments XI, XII, XVIII and XIX) coupled through a timer system.

Figure I.3 Intermittent auditive frequency. Tone pulses with gradual onset used to avoid knocking sensations.

I.2 *Calibration of equipment*

The velocities have been calibrated (and checked during experiments) by three types of instruments.

In experiment I to X by a mechanical r.p.m.-meter.

In experiment VII to X by a voltmeter calibrated in r.p.m. and attached to a motor functioning as a generator on the outgoing shafts of the gear system.

In experiment XI to XIX by a strobotac r.p.m.-meter

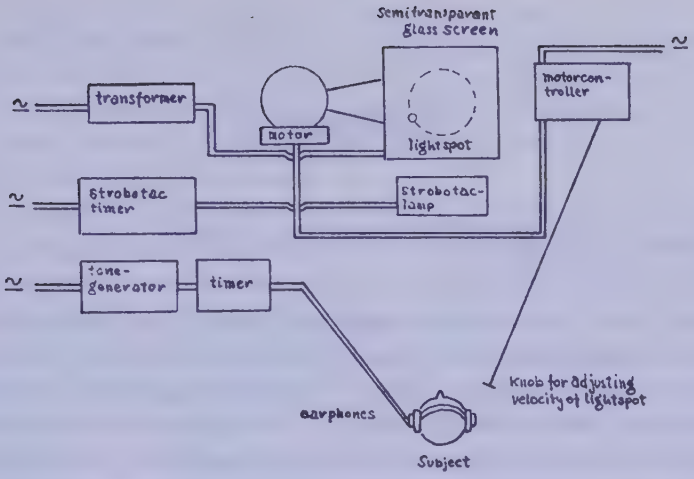


Figure I.4 Apparatus used in similarity matchings (Experiments XVI and XVII).

The intermittent frequencies have been calibrated and checked between experiments by recording the tone- (or light-) pulses on a Mingograph ink writer.

In the measured series (10 measurements at each nominal value) the precision of the equipment is between $\pm$ 1 %.

Appendix II

Fitting a power function to empirical scales from Experiment VII to X

It may seem curious that a work using mainly subjective scaling methods gives hardly any results in the form of S-R plots or psycophysical functions. I have had several reasons for refraining from this form of presentation. The interest is centered on differences between scale-values from loaded and silent velocity. The results obtained show that these differences vary systematically over the range investigated. Individual S-R plots show that the silent scale as a rule is weakly positively accelerated (cf. Mashhour 1964) while the loaded scale is usually weakly sigmoid—see Diagrams 8.10 and 8.11. (It has also been found that the loaded scale is less positively accelerated or more negatively accelerated than the silent scale.)

We thus have curve types describable by the psycophysical power-function $R = c(S\text{-}S_0)^n$, with different degrees of approximation. In view of the criteria, mentioned by Björkman (1960), to be met in order to compute mean curves, the position is weak. Further the scales used here contain few empirical points and although the individual scales have relatively good reliability the material is rather unsuitable for curve fitting. These reasons are sufficient, in themselves, for not using a curve fitting technique.

In spite of this I have, out of curiosity, fitted the function $R = c(S\text{-}S_0)^n$ to individual and group scales from experiments VII to X. I have used the Fortran programme referred to in Chapter 8 (Ottander et al. 1964). The results from these fittings are given in Table II.1.

The results in the table are rather puzzling. Scales that by inspection appear clearly negatively accelerated—e.g. the loaded group curve from Experiment VII, are described by a positively

accelerated function. Some individual scales (e.g. in Experiment X) yield parameter values that are hard to interpret. In spite of this all the fittings are very good. The "absurd" functions have all been controlled and all show one clear minimum when the squared deviation between theoretical and empirical values are plotted against the parameter value for S_o.

The table also shows that the parameters S_o and c are positively correlated, while S_o and n, and c and n are negatively correlated. A negative value on S_o is thus compensated by a low c and a high n. If S_o is varied from $+20$ to -2000 and consecutive determinations are made of the corresponding c and n values, it is found that the solutions all give squared deviations which deviate approximatively $\pm$ 1/1000 000 from the mathematical minimi-solution originally arrived at.

The parameter c is traditionally said to reflect the unit of measurement used (see e.g. Björkman and Ekman (1963)) but these results indicate that the relation is more complicated. The present results illustrate the mistake of carelessly applied fittings of the conventional power-function to empirical data—at least with individual data. Most often a manual fitting procedure is used in which the experimenter implicity evaluates which parameter values are reasonable. An iterative fitting-procedure may thus be ended when the measure of goodness of fit is supposed to reach a minimum and the parameters are still reasonable. One reason for the frequency of this behaviour is that most measures on goodness of fit are relatively insensitive for changes in parameter values.

A data programme naturally lacks these implicit evaluations and may thus give solutions which differ considerably from those usually presented.

The correlation between the parameters can be regarded as ar artifact caused by the precision with which subjects agree in estimates on the lowest stimulus (which is constant for all subjects). The power-function $R = c(S-S_o)^n$ contains one indeterminant parameter which is usually determined by making some rational assumption before the fitting procedure. (Usually it is assumed that $C = 1$ or $S_o = 0$.) The correlation found between the parameters

Table II.1

Individual and group parameter values from fittings of the psycophysical power-function $R = c(S-S_o)^n$.
Data from Experiment VII to X.

Experiment VII

Silent velocity

Subject no.	S_o	c	n
1	—18.638	0.003	1.822
2	— 1.507	0.278	0.767
3	5.707	0.467	0.671
4	1.004	0.287	0.777
5	—17.781	0.024	1.292
6	13.655	0.413	0.818
Group	— 1.543	0.110	1.022

Loaded velocity

Subject no.	S_o	c	n
1	—22.296	0.003	1.777
2	—17.102	0.087	1.002
3	5.473	0.519	0.660
4	—11.609	0.105	0.964
5	—13.643	0.042	1.193
6	19.302	0.464	0.820*
Group	— 9.037	0.065	1.123

* smoothed average over three

Experiment VIII

Silent velocity

Subject no.	S_o	c	n
7	5.109	0.460	0.629
8	—59.656	0.004	1.388
9	—58.503	0.067	0.911
10	12.625	0.389	0.568
11	— 7.945	0.397	0.619
12	—100.610	0.000003	2.665
Group	—12.797	0.130	0.806

Intermittent frequency

Subject no.	S_0	c	n
7	1.722	4.279	0.387
8	—4.188	0.040	2.237
9	—6.443	0.102	1.630
10	—122.880	3.175^{-37}	17.660
11	—0.424	1.635	0.745
12	1.505	4.044	0.346
Group	—1.085	0.962	0.978

Experiment IX

Silent velocity

Subject no.	S_0	c	n
13	—24.484	0.001	1.904
14	11.783	0.485	0.722
15	—31.831	0.003	1.731
16	—10.716	0.276	0.730
17	— 3.000	0.034	1.321
18	9.846	0.368	0.782
Group	— 5.228	0.060	1.151

Loaded velocity

Subject no.	S_0	c	n
13	1.209	0.075	1.162
14	—19.518	0.020	1.342
15	— 7.840	0.038	1.246
16	—25.982	0.095	0.947
17	10.500	0.214	0.973
18	—17.539	0.021	1.360
Group	— 5.904	0.062	1.157

Experiment X

Silent velocity

Subject no.	S_0	c	n
13	—16.185	0.008	1.320
14	— 5.390	0.115	0.896
15			*
16	15.486	3.060	0.144
17	—1596.600	4.646^{-65}	20.193
18	205.130	4.955^{-8}	3.307
Group	—1236.900	1.903^{-48}	15.525

* programme did not converge
Intermittent frequency

Subject no.	S_0	c	n
13	—0.777	0.649	1.272
14	1.563	3.503	0.590
15	—57.039	2.126^{-19}	10.812
16	—115.740	5.548^{-12}	5.764
17	—0.548	0.850	1.141
18	0.145	1.524	0.875
Group	—0.829	0.988	1.028

implies that by assuming a value for c or S_0 the values of the remaining two parameters are also determined.

As mentioned above, a marked interindividual variation is found. A group function is often quite different from the contributing individual functions. See e.g. the individual parameters in Experiment X: S_0 varies between −1600 and +16, c between 4.6^{-65} and 3.5 and n between 0.1 and 20.2. The correlation between the parameters is 1.00.

Without here discussing the mathematical background of the procedure used and the results produced by it, I have, on these grounds, avoided using functional descriptions in the present work.

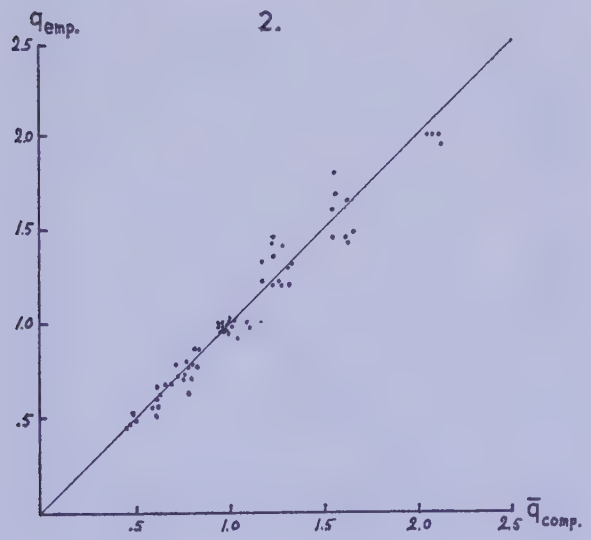
Private communications with several colleagues indicate that this type of dilemma is not confined to my own experiments. This appendix is thus also presented with the thought that someone may wish to investigate these problems further.

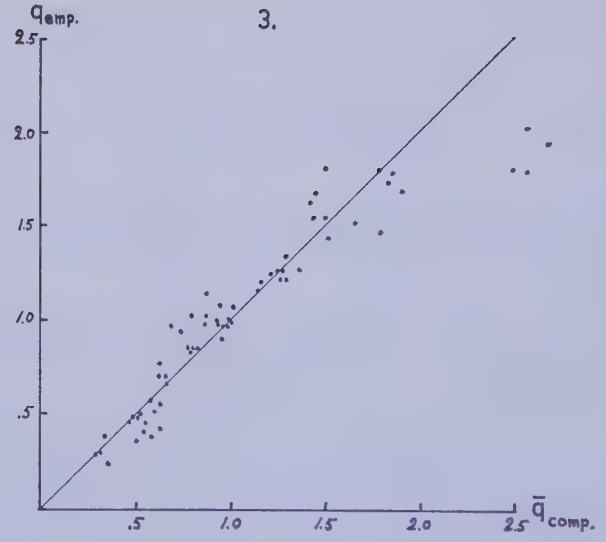
Appendix III

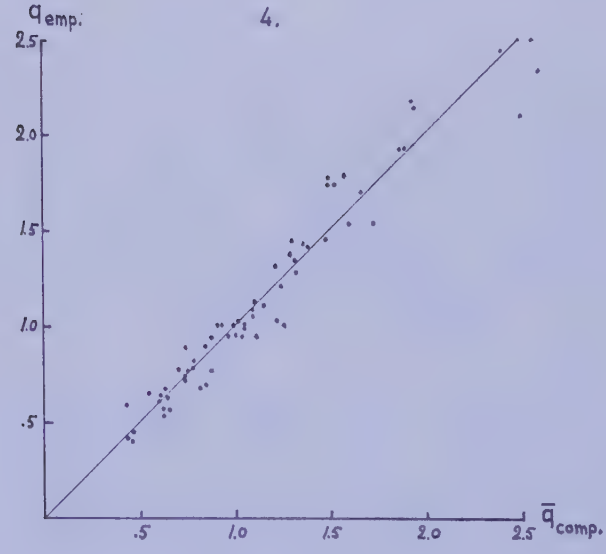
Plots for individuals in experiment XI of computed and empirical ratios

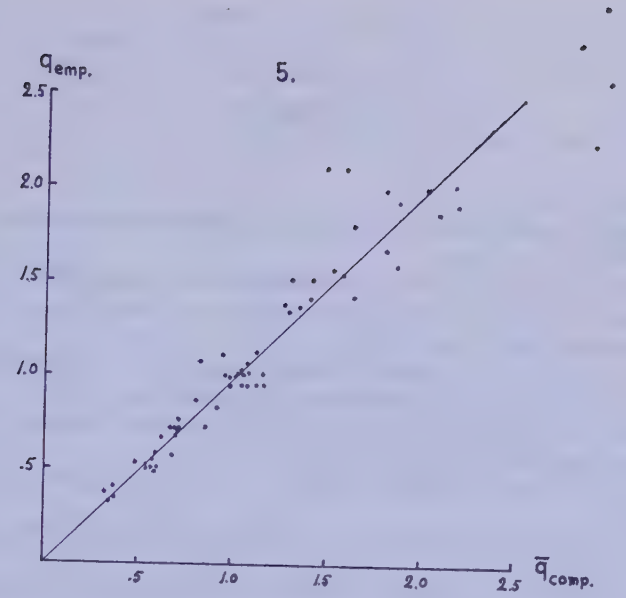
Diagram III.1 Experiment XI, subjects 2, 3, 4, 5 and 6. Arithmetic means of computed ratios ($\bar{q}_{comp.}$) plotted against empirical ratios ($q_{emp.}$).

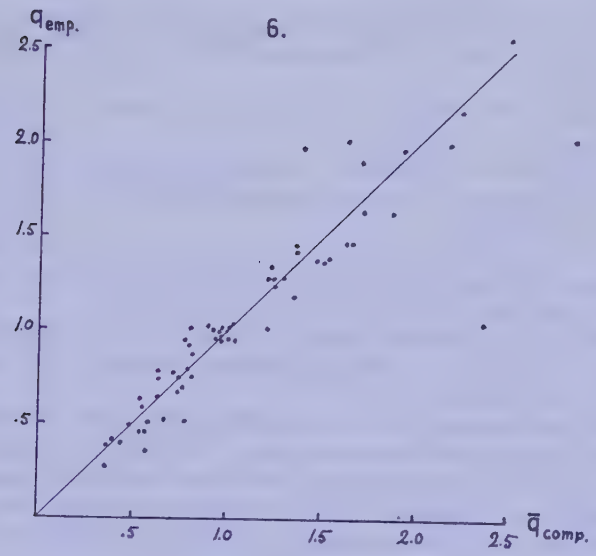
2 = subject 2
3 = subject 3
4 = subject 4
5 = subject 5
6 = subject 6




$q_{emp.}$
3.
2.5
2.0
1.5
1.0
.5
.5
1.0
1.5
2.0
2.5
$\bar{q}_{comp.}$


$q_{emp.}$
4.
2.5
2.0
1.5
1.0
.5
.5
1.0
1.5
2.0
2.5
$\bar{q}_{comp.}$


$q_{emp.}$
5.
2.5
2.0
1.5
1.0
.5
.5
1.0
1.5
2.0
2.5
$\bar{q}_{comp.}$


$q_{emp.}$
6.
2.5
2.0
1.5
1.0
.5
.5
1.0
1.5
2.0
2.5
$\bar{q}_{comp.}$

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